University Of Southern Queensland

Faculty of Health, Engineering & Sciences

Design of Remote Laboratory Experiments for Integration into MEC2402 – Stress Analysis

A dissertation submitted by

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In fulfilment of the requirements of

Courses ENG4111 and 4112 Research Project

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Abstract

Laboratory work has long been regarded as an integral component of engineering education, however, the introduction of distance education has complicated this concept. Remote access laboratories (RAL) have the advantage of allowing students to perform experimental investigations without the need to be physically present. A typical RAL device incorporates computer software/hardware, automation equipment, sensory devices and the internet to perform experiments and provide digital feedback of results.

This project designed and commenced the manufacturing of a physical RAL experimental apparatus. The apparatus has been carefully designed to enhance the educational outcomes for students undertaking the course *Stress Analysis* at USQ. The Course Examiner for MEC2402 proposed the development of a portable, remotely accessible item of laboratory equipment comprising a series of three separate experiments. The chosen experiments demonstrate torsion in a round shaft, bending in an unsymmetric section beam and three-point bending in a rectangular section beam.

By meticulously investigating the relevant pedagogical aspects and mechanical design principals, this project has been able to successfully design the proposed RAL experiments. Following the impending completion of manufacture, the apparatus will be available for the Course Examiners use in future offerings of MEC2402.

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ENG4111 & ENG4112 *Research Project*

Limitations of Use

Certification

I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

Scott Cox

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Signature

20/10/2013

Date

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I would also like to acknowledge Professor David Buttsworth for his substantial contributions towards this project. David's resolute enthusiasm and continual support has been essential to making it a reality.

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Scott Cox

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Symbols & Acronyms

c	Radius / maximum distance from neutral surface
D	Diameter
E	Modulus of Elasticity
g	Standard earth gravity ($9.81\,m/s$)
G	Modulus of Rigidity
$I, I_x, \ldots$	Moment of Inertia
$I_{xy} \ldots$	Product of Inertia
J	Polar moment of inertia
L	Length
M	Moment
P	Force, concentrated load
S_n'	R.R. Moore, endurance limit
S_n	Endurance limit
S_u	Ultimate tensile strength
S_{us}	Ultimate shear strength
S_y	Yield Strength
S_{sy}	Shear yield strength
T	Torque
y	Distance from neutral surface
γ	Shearing strain
ϕ	Angle of twist
τ	Shearing stress
σ	Normal stress
ϵ	Normal strain
δ	Deflection

ALARP	As low as reasonably possible
CHS	Circular Hollow Section
EA	Unequal Angle
FMS	Flat mild steel
GPa	Gigapascal
MPa	Megapascal
N.A.	Neutral Axis
PCA	Principal Centroidal Axis
RAL	Remote Access Laboratory
SHS	Square Hollow Section
USQ	University of Southern Queensland

Chapter 1

Introduction

> *"Engineering is a practicing profession, a profession devoted to harnessing and modifying the three fundamental resources that humankind has available for the creation of all technology: energy, materials, and information. The overall goal of engineering education is to prepare students to practice engineering and, in particular, to deal with the forces and materials of nature."* *(Feisel & Rosa 2005)*

This chapter provides a brief overall understanding of the purpose of this project as well as clearly defining the boundaries of the undertaking. Through analysis of the background, the proposed experiments and the undergraduate engineering course for which they are intended, it is expected this chapter will develop a firm foundation on which to establish the remainder of the project.

1.1 Project Purpose

The ultimate purpose of this project is to design and manufacture a physical experimental apparatus intended to enhance the educational outcomes for students undertaking the course 'Stress Analysis' at the University of Southern Queensland (USQ). The current USQ Course Examiner for *Stress Analysis* (MEC2402) has proposed the development of a portable, remotely accessible item of laboratory equipment comprising a series of three separate experiments. These proposed experiments are further discussed in Section 1.4.

It is the intention of this project to ensure the mechanical design of this equipment is of the highest possible standards in two principal dimensions, physical quality and pedagogical merit. Attainment of the desired high standard for the completed equipment will be achieved through comprehensive investigation of relevant pedagogical aspects in addition to mechanical design principals. This approach is expected to ensure a close alignment between the delivered outcomes and the MEC2402 course learning objectives.

Whilst the core purpose of this project centres on the design and manufacture of a series of proposed experiments it is important to consider the broader objective of this endeavour. Primarily driven by the MEC2402 Course Examiner, the objective is to expose future students of the course to physical experiments and demonstrations. These should be designed to impart a sense of the real world and help reinforce the purpose behind the theoretical aspects taught.

Until 2013, experiments and demonstrations did not form part of the MEC2042 course structure. Student learning was instead based solely on the theoretical concepts presented. The vast majority of topics covered in this course have previously not been practically demonstrated at any time during an undergraduate engineering program at USQ.

The mechanisms and processes by which the Course Examiner's broader aim is achieved are considered beyond the scope of this project. Despite this it is acknowledged that developing an appropriate background understanding critical is to the success of this undertaking. The following Sections 1.2 and 1.3 explore this relevant project background.

1.2 Project Inception

This section provides a brief background of the project origins. A key aspect of this process was to formally establish the intentions of the current MEC2402 Course Examiner with regards to implementation of this project's outcomes into future offerings of the *Stress Analysis*. Documentation of these professional opinions is seen as vital to the analysis of the results of the project, specifically whether the final outcomes align with original task expectations.

The following professional opinions of the current Course Examiner were obtained during a formal interview process. Appendix B provides details of the USQ ethical clearance obtained in order to document the interview outcomes. The Course Examiner has had a total of twenty years academic teaching experience and fifteen years teaching or moderating MEC2402 at USQ

Describe the factors which resulted in the inception of this project.

> *I was eager to convey to students the fact that the theories presented in stress analysis are not just mathematics or physics. The theories presented in Stress Analysis offer reliable engineering approximations which can be used to simulate the real load carrying capacity and deflection of a range of simple structures in many applications. Without an exposure to experiments which physically demonstrate such reliability, students may fail to appreciate the value of such engineering analyses (Buttsworth 2013).*

Based on your past academic teaching experience do you believe students benefit from exposure to laboratory experiments and demonstrations?

> *Yes. I believe carefully designed laboratory experiments should be integrated with the coursework to which they relate and can effectively reinforce theories, enhancing learning outcomes. Many engineering students seem to have little experience to laboratory or field hardware, so additional exposure to such equipment is surely a good thing (Buttsworth 2013).*

During the 2013 offering of the course a simple experiment rig was used to perform and record in-class demonstrations and experiments based around a number of key topics covered in *Stress Analysis* (see Figure 1.1). In addition, data was taken from these experiments and presented electronically so as to form part of the course assignments. The introduction of this temporary experimental rig was used to further develop the requirements of the proposed remote laboratory apparatus.

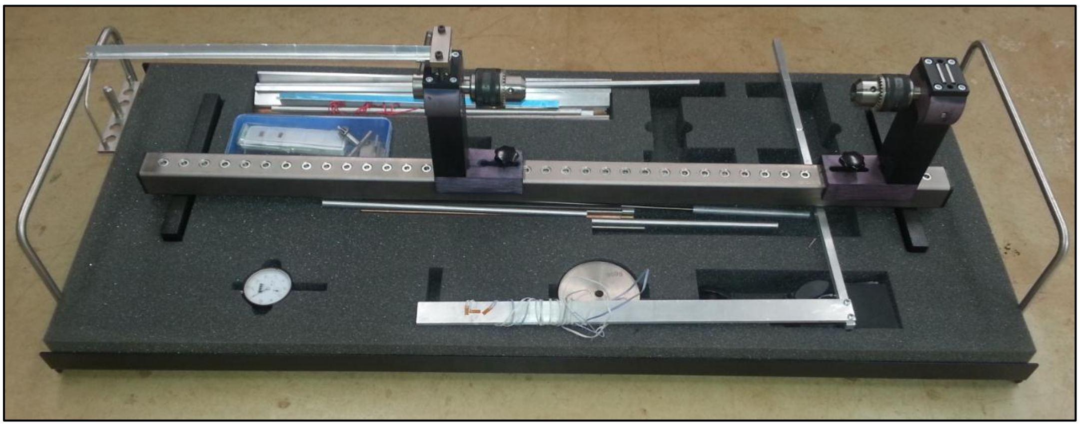


Figure 1.1 - Experimental rig introduced into MEC2402 in 2013

Describe the effectiveness of the implementation of the existing experimental rig in the 2013 offering of the course.

> *I was pleased with the demonstrations that were performed in the 2013 offer of Stress Analysis. Although I was unable to offer students the opportunity to engage with the hardware on a personal level, having the analysis of results from the demonstrations as a corner-stone question in each of the three assignments was good. Students engaged in discussions on study desk to tease out the essential information and define the assumptions that needed to be made in order to proceed with the analysis. A feature of each of the demonstration questions was a request for students to reflect on the reliability / accuracy of the analysis. The depth of the responses offered by many students indicated a level of engagement with the work which does not occur when students provide solutions to simple textbook-like questions (Buttsworth 2013).*

With respect to apparatus design, what key aspects would you consider vital to the successful implementation of laboratory equipment?

1. *Safety*
2. *Accessibility, the capacity for students to personally experiment with the apparatus.*
3. *Capacity to demonstrate the reliability of theoretical analyses.*
4. *Integration with relevant coursework (Buttsworth 2013).*

Briefly describe the reasoning behind the selection of the three proposed experiments.

> *The three proposed experiments align with Stress Analysis coursework and can form a significant component of each of the 3 assignments (Buttsworth 2013).*

What do you hope to gain through the use of remote access technology?

> *I want to offer all students – on-campus and external – the learning benefits that can follow from exposure to physical hardware and reinforce the value of Stress Analysis to aspiring engineers (Buttsworth 2013).*

1.3 MEC2402 - Stress Analysis

MEC2402 - Stress Analysis is a course undertaken by a significant number of University of Southern Queensland (USQ) students. This body of students includes all those completing a Mechanical, Civil, Mechatronic, Environmental and Agricultural Bachelor of Engineering Major. The principle topics covered in the course include the relationship between stress and strain within engineering materials and structures and how to calculate either in a given situation. *Stress Analysis* also addresses the stability and strength of machines and structures while under load (USQ 2013). MEC2402 - *Stress Analysis* has four primary course objectives which define expected student learning outcomes. USQ (2013) outlines these as:

1. *Review and apply the principles of static equilibrium to the analysis of structures such as pressure vessels, beams and torsion members.*

2. *Evaluate stress and strain within various structures by applying appropriate engineering theories.*

3. *Formulate solutions to problems requiring the application of suitable engineering theories for stress and strain*

4. *Locate and calculate the highest equivalent stress on any section of a beam or shaft undergoing simple or combined loading, and determine if yield failure will occur*

Since 2009, an average of 228 students per year have enrolled to study MEC2402 at USQ (refer to Appendix C). From this total number of students, an average of 149.6 students have been considered as 'external' with the remainder studying on-campus at either the Toowoomba or Springfield campus. Figure 1.2 represents this average distribution. Clearly 'external' students form the largest component of the overall student cohort.

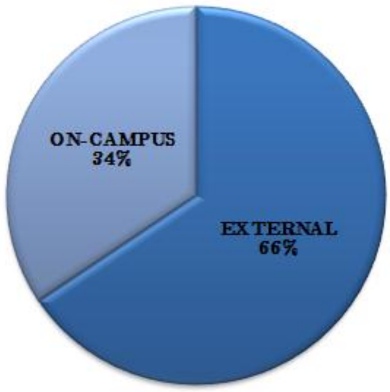


Figure 1.2 - Average distribution of MEC2402 course delivery methods since 2009

Stress Analysis is designated as a second year course in all relevant engineering disciplines at USQ. The course has CIV1501 (Engineering Statics) as a pre-requisite. MEC2402 introduces students to a large number of new and challenging concepts designed to develop theoretical understanding required in subsequent courses from each disciplines. Topics covered in the course include:

- Normal stress and strain
- Pressure vessels
- Shear Stress and strain
- Torsional members
- Stress analysis
- Strain analysis
- Theories of elastic failure
- Normal stress in beams
- Shear stress in beams
- Combined loading
- Elastic plastic analysis
- Buckling

MEC2402 is considered to be an academically challenging course. To highlight this concept, Figure 1.3 draws a comparison between the averages of student grades in Stress Analysis compared with the average distribution of grades across all USQ engineering courses as provided by Ahfock (2013). It is important to note the data used to generate this plot only considered students who participated in all course assessment items. Appendix C provides details of the data used for the MEC2402 results.

As Figure 1.3 shows, MEC2402 has on average, significantly fewer HD, A and B grades and more C and F (fail) grades than the USQ average for engineering courses. This is seen as a clear reflection on the level of difficulty students associate with completing *Stress Analysis*.

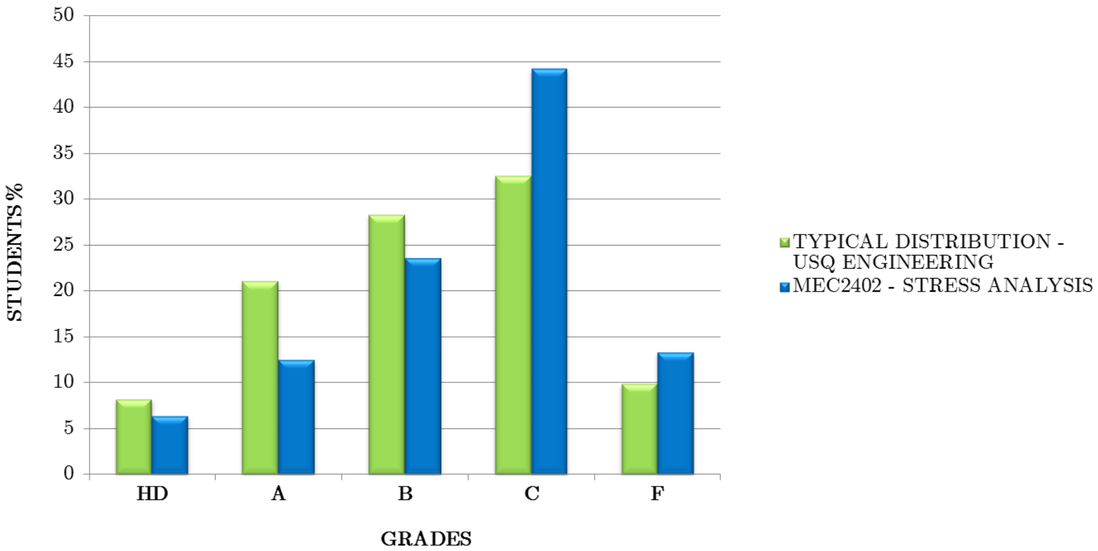


Figure 1.3 - Comparison of average MEC2402 grade distribution

1.4 The Proposed Experiments

A series of three individual experiments mounted on a single portable frame have been proposed by the Course Examiner based on his extensive academic teaching experience. It is proposed that these three experiments should, instead of being physically manipulated by students, be automated and configured for control either locally or remotely through the use of the internet and a computer interface. This is commonly referred to as either a *remote access laboratory* (RAL) or simply a *remote lab.*

Remote labs have emerged during the last decade as an important educational resource (Lowe et al. 2012a). Their necessity results from the introduction of systems of distance education in undergraduate courses. Remote labs enable students to perform investigations using real experimental equipment. However unlike traditional hands-on experiments, remote labs do not require students to be physically present to participate. A typical remote access laboratory incorporates computer software/hardware, automation equipment and sensory devices to perform experiments and provide digital feedback of results.

Given the significant number of *remote* or external students typically involved in *Stress Analysis* each year it is likely the use of remote access technology will offer important advantages to engineering students at USQ. In addition to increased accessibility, advantages also include a high level of user safety and equality of learning outcomes for all students whether on-campus or external. Learning outcomes expected through the use of RAL systems is further investigated in Chapter 2.

Through the use of remote access technology it will be possible to design and construct the desired experimental apparatus to maximise student and staff safety. Considering manipulation and measurement of all experimental parameters will be achieved electronically, the use of appropriate guarding could isolate users from harm whilst permitting complete visual inspection of results. Improved user safety is seen as a significant advantage of configuring the proposed experiments as a *remote lab*.

The three proposed experiment concepts are arbitrarily numbered and briefly described in the following Subsections 1.4.1 through 1.4.3.

1.4.1 Experiment One – Shaft Torsion

This experiment will physically demonstrate the elastic-range and angular deformation associated with applying a torque to a member of circular cross-section. In addition the experiment should be capable of analysing the strains and therefore stresses induced within the material by the load conditions. These real-life measurements will demonstrate a close correlation to values theoretically predicted through appropriate *Stress Analysis* calculations.

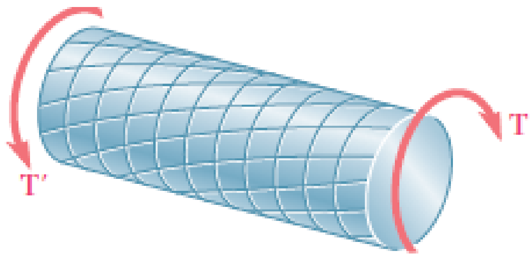


Figure 1.4 - Deformation due to torsion in a circular shaft (Beer & Johnston 2009)

1.4.2 Experiment Two – Unsymmetric Bending

This experiment will demonstrate the concept of unsymmetrical bending in a cantilever beam section. This should involve the student theoretically calculating the orientation of the principal centroidal axes (PCA's) and the neutral axis (N.A.) for a given cross-section and load condition. Results will then be compared to experimental measurements to reinforce the student learning experience and understanding of the concept.

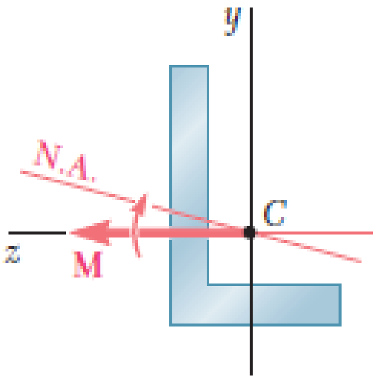


Figure 1.5 - Bending of an unsymmetric section (Beer & Johnston 2009)

1.4.3 Experiment Three – Normal Stress in Beams

The third experiment will demonstrate a number of phenomena associated with the application of an internal bending moment to a statically determinate, constant cross-section beam. It is proposed that a simply supported, centrally loaded configuration would provide the most valuable student outcomes for the introduction of these topics. These loads would be limited to maintain stress within the elastic limit of the material.

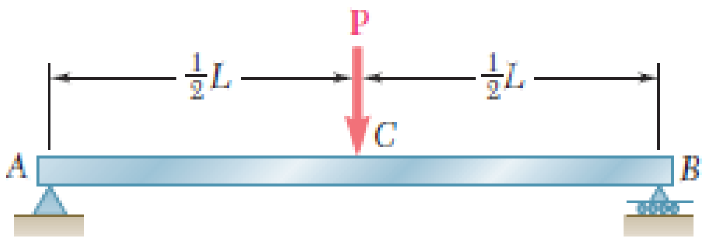


Figure 1.6 - Beam subject to a concentrated mid-span load (Beer & Johnston 2009)

1.4.4 Additional Requirements

In addition to requirements already identified, a number of other characteristics are critical to achieving a successful design for the complete apparatus. Several key design objectives are listed below. A complete list is presented in Section 3.2.

1) **Limited overall physical dimensions**
   It has been requested by the Course Examiner that the complete rig should be relatively small, based on a desire to transport the device around the USQ campus/s if required. As such the completed unit must be able to easily fit through standard doors and into lifts. This parameter will therefore be the primary consideration governing the size during design work.

2) Ease of transport

The design of the rig should readily enable transport around any USQ campus. It is suggested that the rig should be mounted on wheels fit for this purpose and provisions be included to facilitate this type of manual handling. In addition the total mass of the completed unit must be within a range suitable for handling by a minimum of one person.

3) Strong correlation of physical results with theory

A core purpose of this project is to design and construct experimental equipment which will provide a link for students between real phenomena and theoretical concepts presented in MEC 2402. As such it is seen as vital to ensure the results obtained and observed are highly repeatable and within an appropriate range of accuracy. Failing to achieve this requirement will likely negate any benefits associated with physically demonstrating related theory.

4) Achieve high quality results within provided budget

The implementation of this project requires a significant financial input from USQ. Whilst the development and application for a suitable budget have not been included in this document, strict budget constraints have been imposed. As a result, care must be taken throughout to ensure the effective use funds. Although the design phase of this project is to be conducted free-of-charge, all costs associated with the manufacture and commissioning of the device will be covered by USQ. Conducting high-quality design work will be crucial to achieving this requirement.

1.5 Initial Design Concept

In order to ensure the reader gains a suitable perception of the overall design concept, Figure 1.7 shows a solid model generated early in the project to support project approval and funding. The reader should note the following key aspects of the model.

- **Transparent cover –** (shown opaque) under which the three proposed experiments are mounted. This cover will eliminate potential risks to users during laboratory operation.
- **Touch screen PC –** Used for local control of the experiments in addition to experiment control during remote access.
- **Electrical enclosure –** Containing all automation control equipment
- **Frame –** Base onto which experiments, touch screen PC and electrical enclosure are mounted. Note the inclusion of castors (shown in yellow) to facilitate ease of transport.

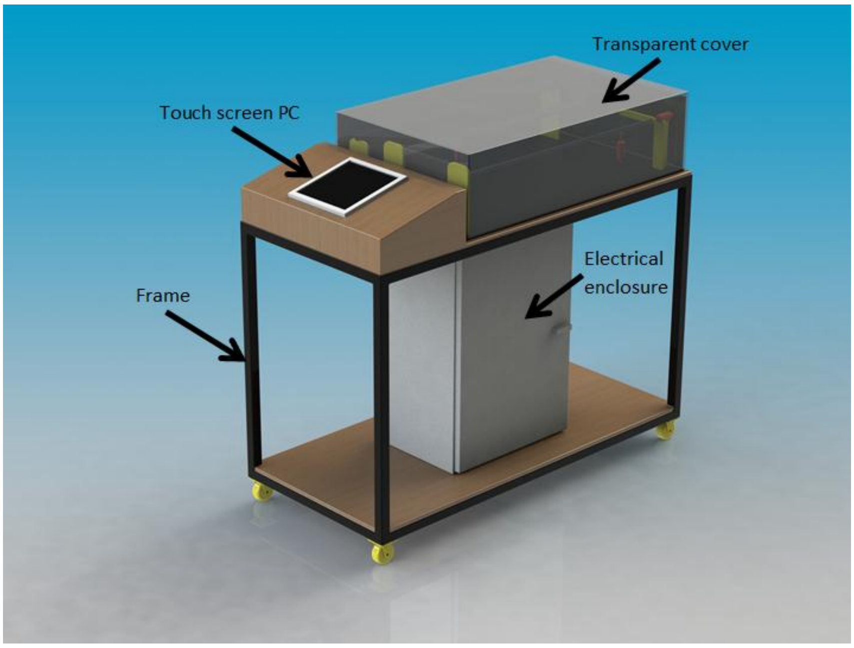


Figure 1.7 - Initial remote access laboratory apparatus design concept

1.6 Project Scope

The following section aims to clarify what this project intends to achieve. Given the nature and complexity of the undertaking it is important to clarify these boundaries to provide some perspective of the intended project.

Firstly it is important to separate the intensions of this research project with the project as a whole to which it contributes. Specifically, this research project intends to establish the requirements of the proposed laboratory apparatus, investigate relevant pedagogical issues, perform and present all required mechanical designs and supervise the manufacture of the device. The following components of the design and manufacture are outside the scope of this research project.

- Application for the required funding
- All electrical design work including programming of control systems.
- Electrical wiring work
- Computer interface design.
- Design work associated with enabling remote access of the experiments.
- Method by which it is incorporated into MEC2402

The intention has been to complete apparatus manufacture within the timeframe of the research project. Despite this, final outcomes have been limited by a number of external factors. These include timeline for the application and approval of the required funding and the availability of all required goods and services. As a result, manufacturing work will continue after the date of thesis submission.

This project clearly aims to establish a case supporting the development of this apparatus via a thorough investigation of literature relating to this subject. This literature review component will serve as a foundation for the design process.

1.7 Research Objectives

This dissertation aims to achieve a number of research objectives. The primary research objectives are to:

A. Formally establish the opinions of the MEC2402 Course Examiner with respect to the introduction of an experimental component of the course and how it is believed this will advantage future *Stress Analysis* students

B. Establish whether each of the specific experiments outlined in Section 1.4 can be designed and manufactured on a small scale using commercial automation hardware to provide results that demonstrate a strong correlation with the theory presented in MEC2402.

1.8 Summary

This chapter has provided a brief overall understanding of the purpose of undertaking this project as well as clearly defining the boundaries of the task. This research project specifically intends to design and manufacture a physical remote access experimental apparatus intended to enhance the educational outcomes for students undertaking the course *Stress Analysis* at USQ. The apparatus should include a series of three separate experimental concepts as selected by the MEC2402 Course Examiner.

This research project is defined by the following requirements:

- Establish the requirements of the proposed laboratory apparatus
- investigate relevant pedagogical issues
- Perform and present all required mechanical designs
- Supervise the manufacture of the device as time permits.

Chapter 2

Literature Review

2.1 Introduction

The following chapter reviews literature relevant to the implementation of a laboratory component into undergraduate engineering education. The review will initially aim to provide a background into laboratory style education from a historical and modern day stand point. Considering the objective of this project is to generate the designs for a series of remote access experiments the investigation will consider the benefits and draw-backs associated with the technology. As part of this process comparison will be drawn between the remote access of physical experimental equipment and the use of virtual simulations as a potential solution. Finally a number of documents relevant to the design of the equipment shall be reviewed including appropriate Australian Standards and MEC2402 course materials.

It is seen as essential to thoroughly investigate all literature relevant to this research project. Developing a context within which project sits, will enable independent assessment of the appropriateness of the proposed remote access laboratory design.

2.2 Laboratories in Engineering Education

This section investigates literature relating to the use of laboratories in engineering education. Topics covered will include the history, effectiveness and current trends in this area.

Mackechnie and Buchanan (2012) suggest most universities use laboratory education as an essential part of the undergraduate engineering curriculum. The role and nature of this style of education is however rapidly changing and being complicated by a number of factors (Feisel & Rosa 2005). The introduction of systems of distance learning programs, in particular has resulted in many new developments in this area. This trend has in turn generated a reinvigorated debate amongst authors as to the fundamental objectives of laboratory style education.

2.2.1 History

Laboratories have long been used as an integral component of an undergraduate engineering education (Grayson 1993). Even before the establishment of formal systems of education, practical experience has been the cornerstone of the engineering profession. Feisel and Rosa (2005) indicate that engineering was originally taught in an apprenticeship style system in which students learnt through designing, analysing and building their own projects. This education was based almost entirely on practical observations.

Systems of formal engineering education began to appear in universities around the world in the middle of the eighteenth century (Johnston 1999). These institutions established curricula that placed substantial influence on laboratory instruction. Feisel and Rosa (2005) suggest that from these early years, tension between the theory and the practical elements of education began to arise. Despite this Stephan (2002) found that drafting and laboratory work remained central parts of the engineering curriculum up until the end of the Second World War.

Following these years of conflict, a large number of inventions that occurred as a result of the war were developed by individuals educated as scientists rather than engineers (Feisel & Rosa 2005). As a consequence the American Society for Engineering Education (ASEE) appointed a committee to recommend a course of action to ensure engineering education kept pace with developments in science and technology. The committee's findings, known as the *Grinter Report*, determined that engineers where being produced too practically orientated and not sufficiently equipped to seek solutions from first principles (ASEE 1955). It was recommended by the committee that engineering educators needed to concentrate on developing students' abilities in scientifically based subjects such as mathematics, chemistry and physics.

Feisel and Rosa (2005) indicate that these recommendations were quickly adopted by the American Engineer's Council for Professional Development (ECPD). This resulted in a rapid shift in the style of the typical engineering education. Focus moved from practical aspects of engineering education including laboratory work to more academic and theoretical subjects. As a result engineers soon began to graduate highly competent in theory yet lacking in practical ability. This imbalance was formally recognised in ASEE reports released in 1967, 1986 and again in 1987.

2.2.2 Current Trends

It is well documented that despite decades of intention to improve the quality of laboratory components in engineering schools many inadequacies currently remain. King (2008) published the findings of a comprehensive report on the outcomes of a project by the Australian Council of Engineering Deans (ACED) into the supply and quality of engineering graduates for the 21st century. The report found that many Australian universities need to urgently upgrade or renew their engineering laboratory facilities. Students had noted situations where out-of-date and unreliable equipment was being unacceptably used to demonstrate engineering principles and measurement techniques. The report also noted that many international academics and some students had been exposed to far superior laboratory experiences and equipment in their home countries than could be found in most Australian universities.

Another recent report published by Kostulski and Murray (2010) focused on the results of a national engineering laboratory survey involving all Australian universities offering undergraduate engineering programs. The report outlines a number of key findings which highlight current laboratory trends. Selected outcomes are summarised below:

- Academic staff often rank practical sessions as the most essential component of their subjects however acknowledge a general lack of focus in this area.
- Successful delivery of project-based laboratory work is increasingly reliant on flexible student access.
- Technical staff suggested specialised, inflexible laboratories are most prone to under-utilisation.

Whilst it is apparent that further attention needs to be directed at improving the overall quality of laboratory education in engineering programs, a large number of authors have published work focusing on another aspect of current laboratory trends. Feisel and Rosa (2005), Ma and Nickerson (2006) and Corter et al. (2007) all indicate that the role of the laboratory in engineering education has undergone a rather rapid transformation in recent years. The modern trend in laboratory developments is divided between the use of hands-on, simulation or remote-access experiments (Corter et al. 2007). A significant amount of literature can be readily identified which deals with the issues associated with introduction of these diverse styles of laboratory experience.

Ma and Nickerson (2006) completed an extensive literature review of on these three laboratory styles and provide excellent interpretations of the characteristics which define each. Hands-on labs are distinguished by two particular attributes. Firstly that all equipment required is physically set up and secondly that the students performing the experiments are physically present in the lab. Simulated labs are distinctly dissimilar to hands-on labs as they are purely imitations of real experiments. Computers are used to digitally 'simulate' the results expected in practise without the presence or manipulation of any physical hardware.

Remote labs on the other hand are similar to hand-on laboratories and are characterised by mediated reality. Similar to hand-on labs, they still require physical experimental equipment. The difference however is that remote labs offer the potential for geographical detachment of users. Fujita, Cassaniga and Fernandez (2003) and Gustavsson (2002) indicate that remote labs are becoming more popular.

Ma and Nickerson (2006) assert that there are advocates and detractors for each of these three laboratory styles. This sentiment is also shared by Corter et al. (2007).

2.3 Effectiveness of Laboratory Education

There is general acceptance amongst educators as to the value of practical laboratory work in engineering education (Feisel & Rosa 2005). This notion is further supported by Corter et al. (2007) who suggests engineering educators believe hands-on experiences form a necessary supplement to the more passive experiences such as attending lectures and reading text books. In addition Doughty (1992) indicates that practical experiments are key to the relationship between meaning and understanding.

Edward (2002) conducted a study and review of student and staff perceptions of laboratory tasks in engineering education. The study concluded that engineering students see laboratory work as a vital component of their education as they often perceive themselves to be involved in a career path that is practically orientated. This concept was reinforced by Doughty (1992) who found that separating practical work from theoretical lectures created division in the mind of students instead of creating the valuable links between theory and practical application which often reinforces basic concepts. This notion was further supported by Edward (2002) who went on to indicate that many academic staff consider that labs typically afford engineering students with 'a feel for what the numbers mean' beyond what worked theoretical examples can provide.

Edward (2002) continued by suggesting that considering the majority of engineering students expect to find future employment in industry rather than as researchers it is important that the design of laboratory apparatus reflect industrial needs. The study also determined that a well-designed laboratory experience may form the "cement that binds the student's curriculum together and may make an invaluable contribution to the engineer's professionalism".

Despite the large amount of published literature supporting the use of laboratories in engineering education only a relatively small body of work exists into the actual effectiveness of the methods. This perception is supported by Edward (2002) and Lowe et al. (2009). Corter et al. (2007) proposes that this is due to lab experiments often being built by engineers or scientists who typically write about technical design matters rather than issues relating to educational effectiveness.

Although there is seemingly unanimous support amongst authors and educators for the use of physical experiments, there is however widespread disagreement about the effectiveness of using new technologies in laboratory design (Corter et al. 2007). This relates particularly to the implementation of simulations and remote access technologies as a substitute for traditional hands-on experiment.

Imbrie and Rahhaven (2005) argue that there is no significant difference between the education outcomes achieved through the use of remote access laboratories when compared to physically carrying out an experiment. This position is supported by Sonnenwald, Whitton and Maglaughlin (2003) who demonstrated through evaluation of conceptual learning that remote laboratories are as effective as hands-on experimentation. In contrast, a number of authors are critical of remote labs such as Keilson, King and Sapnar (1999) who argue that students are likely to be distracted and impatient with the computers. In turn this will harm the student's engagement with the experiment.

The effectiveness of simulated labs appears to be the most emotive amongst authors on this subject. While advocates initially championed simulations as the solution to increasing expenses of physical laboratories they now see them as being more efficient and of equal effectiveness as traditional laboratories (Ma & Nickerson 2006). Critics of this style of laboratory on the other hand propose that exposure to simulations will result in students developing a distinct disconnect between the real and virtual worlds (Magin & Kanapathipallai 2000). It is also noted by Canizares and Faur (1997) that the costs of developing simulation are not necessarily lower than real labs.

2.4 Simulation vs. Physical Experimentation

Considering a physical remote-access experimental rig has been proposed for this project, it is seen as valuable to undertake a short review of the literature relating to the comparison of simulations and physical experimentation.

Firstly it is important to clarify the terms involved. 'physical experiments' relate not only to traditional hands-on experiments but also the use of technology to manipulate physical laboratory equipment remotely, via the internet. Remote laboratories are similar to hands-on in that they are part of the real world and reflect physical devices (Koretsky et al. 2008). This differs dramatically from simulation technology in which mathematical models are used to digitally replicate physical phenomena (Koretsky et al. 2008). Corter et al. (2007) believe that even though simulations have been widely adopted in education; the majority of educators feel they lack important pedagogical characteristics. It is generally agreed that currently, physical experiments cannot be completely replaced by simulations (Feisel & Rosa 2005).

Jona et al. (2011) conducted a comparative study into the financial and pedagogical costs associated with physical experiments (primarily remote access) and simulations. The study found that while not as cost effective, student interactions with real experimental equipment typically afforded them a greater sense of reality, higher trustworthiness of data and more authentic inquiry into results obtained compared to a similar experiment with simulated data. It was also determined that the student involved in the study naturally associated physical experiments with real error and therefore acknowledged, analysed and reasoned with the variability in their data. In contrast simulated labs were seen to inhibit such questioning.

Marshall and Young (2006) summarised from their study that simulations tended to cause test subjects to focus purely on quantitative output of results rather than the more natural plan-test-theorise cycle associated with physical experimentation. These observations were also noted by the earlier work of Roth, Woszczyna and Smith (1998).

Considering the literature presented in this section it is clear that constructing a physical experiment is the best option for improving educational outcomes for future students of *Stress Analysis*. Considering the aim of the Course Examiner to impart a sense of the 'real world' to students it is clear that performing simulations of the proposed experiments would not serve to reinforce student understanding but merely graphically depict the text book theory.

2.5 Remote Access Laboratories

The emergence of technologies that has allowed the monitoring and manipulation of physical laboratory equipment has facilitated recent developments in remote access laboratories (Lowe et al. 2009). An investigation into the literature surrounding remote access laboratories yields a large body of work. This section aims to provide an appropriate overview of the subject to impart an elementary understanding of the technology and its place in engineering education.

2.5.1 Background

As undergraduate engineering programs began to be offered via distance education the issue arose of how to deliver students the necessary laboratory experience required (Feisel & Rosa 2005). Bengiamin et al. (1998) suggest that the usual approach to this problem was to have students perform laboratory exercises at other nearby institutions or in concentrated on-campus laboratory courses. Despite the introduction of numerous early technological additions to distance education such as video recording and computers, nothing changed the practise of distance education as much as the advent of the internet (Feisel & Rosa 2005). The internet combined with the emergence of commercial automation hardware facilitated the development of remote laboratories (Corter et al. 2007).

The mid 1990's saw the earliest examples of the use of remote access technologies to manipulated physical laboratory experiments (Aktan, Bohus & Crowl 1996), (Lowe et al. 2007). Shor, Bohus and Atkan (2011) provide a comprehensive historical background on the development of the first remote laboratories in education with which they were heavily involved. In generally however, there is very little published literature on the history of remote access laboratories. Despite this, it is clear that remote labs are becoming more popular (Gustavsson 2002), (Fujita, Cassaniga & Fernandez 2003).

Lowe et al. (2012b) suggest that over the last 15 years an increasing amount of attention has been directed towards providing remote access to physical laboratory apparatus. Early research into this technology predominantly focused on the technical evolution however has shifted in recent times towards an emphasis on pedagogic aspects. This is confirmed by El-Sayed and Sven (2010). Despite this trend, it has been noted by Lowe et al. (2007) and Corter et al. (2007) amongst others, that there currently remains a lack of conclusive research on the subject.

Regardless of these, issues Lindsay and Stumpers (2011) firmly assert that remote laboratories are becoming an increasingly credible addition to modern engineering education programs. Remote access laboratories are now in use in many engineering schools across the world (Corter et al. 2007).

2.5.2 Current Global Position of the Technology

Lowe et al. (2008) indicate there has been growing worldwide interest in the use of remotely accessible laboratories. Remote labs are now operating in a large number of universities around the world. The most cutting-edge examples are current found at The University of Technology Sydney (UTS) and The Massachusetts Institute of Technology (MIT). This is confirmed by Zubia and Alves (2011) who also mentions the LiLA project in Europe as amongst the most important remote labs for engineering education. In addition Jona et al. (2011) draws reference to the newly formed Global Online Labs Consortium (GOLC) which seeks to combine the resources of these and other institutions.

Considering remote labs allow students to remotely interact with real laboratory equipment irrespective of their physical location the primary global focus has been on developing the concept of large-scale, cross-institutional sharing of facilities (Lowe et al. 2009). The following is a summary of the previously mentioned world-leading facilities in the sharing of remote access laboratories.

iLab (MIT, USA) – Initially commencing in 1998 with a single semiconductor experiment, iLab now includes are large range of science and engineering labs covering topics such as microelectronics, chemical engineering, polymer crystallisation, structural engineering and signal processing (MIT 2013). To date, iLabs have been used by over 4,500 students for the completion of credit-bearing assignments (MIT 2013)

Labshare (UTS, Australia) – Labshare is a not-for profit venture funded by the Australian Government Department of Education, Employment and Workplace relations. Lowe et al. (2009) state that the mission of Labshare is to create a nationally shared network of engineering remote laboratories. The project is led by UTS as a joint initiative also involving Curtin University, UniSA, RMIT and QUT (Lowe et al. 2009). The UTS Remote Laboratory facility is the largest of its kind worldwide and comprises a total of more than 40 separate experiments across engineering and science (UTS 2013). Despite this only a small portion of these experiments are currently available via the Labshare project.

LiLa (Europe) – LiLa is an acronym for 'Library of Labs', an initiative of eight European universities and three enterprises for the mutual exchange of remote and virtual laboratories. The primary target groups of the project are university teachers and students of natural sciences and engineering. LiLa currently comprises of a total of 14 separate engineering experiments (LiLa 2013).

Global Online Labs Consortium (GOLC) – GOLC was recently formed at MIT with the purpose of promoting the development, sharing of, and research into remotely accessible laboratories for educational use. The consortium currently has 18 voting member institutes included all those involved with the Labshare, iLab and LiLa projects.

While a review of literature into the current global position of remote lab technology was able to find anecdotal evidence of these and other current examples, published literature with specific details of all universities world-wide who have implemented the technology appears scarce. It is evident however that a large number of universities are currently using or planning on implementing the technology. Australian universities alone with remote lab facilities include the University of Technology Sydney, Curtin University, University of Southern Queensland, University of Queensland, Queensland Institute of Technology, University of South Australia, Royal Melbourne Institute of Technology and Swinburne University (Lowe et al. 2008).

As a final note on this topic, it is of interest to mention that whilst several examples of simulation are commercially available there currently exists no off-the-shelf remote laboratory systems available for purchase (Ma & Nickerson 2006). This lack of availability has also been confirmed for the present year by conducting a comprehensive internet search on the topic. As a consequence Ma and Nickerson (2006) believe that all remote labs in use today have been custom made to suit the desires of academic staff.

2.5.3 Pedagogical Aspects

Prior to delving into this subject area it is seen as appropriate to formally define the term ‘pedagogy’ to ensure the reader is familiar with the term. (Oxford 2013) define pedagogy as ‘the method and practice of teaching, especially as an academic subject or theoretical concept’. In short, pedagogy refers to the art or science of teaching.

Lowe et al. (2012b) assert that early research into remote laboratories centred on technical evolution as opposed to the associated pedagogical implications. Research into remote laboratories has recently begun to shift towards consideration of the pedagogical elements involved (Lowe et al. 2012b). A study of the available literature in this area seems to indicate generally favourable views towards remote access technologies from this point of view. This is particularly true when comparisons are made between simulations and remote access of physical experiments.

In their short paper on student perceptions of remote labs Jona et al. (2011) argue that there are unique educational advantages to using remote labs in place of simulations. These include providing an understanding of the influence of error and natural variability in experimental data. This review will however concentrate on available literature which draws a comparison between remote labs and hands-on experiments given the seemingly unanimous support for this traditional laboratory style as established in Section 2.3.

Whilst most authors on the subject of remote lab pedagogy do not explicitly discuss the matter, it is clear that the ultimate goal of advocates of the technology is to prove that it is at least as effective as traditional hands-on labs. Sonnenwald, Whitton and Maglaughlin (2003) for instance stated, as a result of their thorough investigation of conceptual learning, that remote labs where just as effective as hand-on. In addition other authors such as Ogot, Elliot and Glumac (2003) and Corter et al. (2004) demonstrated that the differences in learning outcomes associated with one lab environment versus the are not significant.

Bright et al. (2008) state that while the transition towards increased usage of remote labs may appear on the surface to be a simple change of access mode, there are a wide range of factors at play. The environment in which learning occurs whether online or face to face involves a complex array of factors that influence learner achievement and satisfaction (Stein & Wanstreet 2003). Bright et al. (2008) believe that if these factors are not properly considered during the design of a laboratory experience have the potential to significantly affect student learning outcomes. Their study reviews these factors and the impact each may have on learning outcomes. The primary conclusion of the work is to assert that the complexity of the factors should not be underestimated.

Despite this cautious position it is agreed by Bright et al. (2008) in addition to Ma and Nickerson (2006) that remote labs have a clear ability to expand the reach of pedagogy to large numbers of geographically dispersed students. Furthermore considering the trend towards substantial sharing of facilities amongst institutions, remote labs can provide students with experiences that would have otherwise been financially or logistically inaccessible (Lowe et al. 2009). In addition to these suggested benefits Lowe et al. (2012b) argue that remote access laboratories provide an exciting opportunity for educators because the interaction between student and experiment are now mediated through computer software. In this way it is believed that educators now have greater control over pedagogical aspects of the student laboratory experience.

Lindsay and Stumpers (2011) continue further by suggesting that remote laboratories offer significant advantages over traditional hands-on experiments. These advantages are said to include a large improvement in pedagogical efficiency by eliminating the human setup and tear down time associated with many hands-on experiments. It was even stated by Esche (2002) that “it is pedagogically advantageous to conduct open laboratories where students can return later at their personal discretion and convenience to repeat and refine their experiments as required”.

In conclusion, a review of the literature in this area clearly indicates that the study of pedagogical aspects of remote labs is currently an area of strong research interest. Many authors have published statements calling for more conclusive work on the subject before a conclusive judgment can be made. Despite this, the sentiment of the vast majority of authors appears overwhelming in support of the technology.

2.5.4 Design

Considering this literature review seeks to form the basis of this projects design process, it is seen as important to investigate literature which relate specifically to this subject. Despite this intention however the investigation has revealed a significant lack of quality technical data relating to the design of remote-access laboratories. This is particularly true of literature relating to the 'physical' design of experimental rigs. Available literature instead focuses on the importance of experiment design with regard to meeting laboratory learning objectives. Feisel and Rosa (2005) for instance state that "designing a laboratory experience without clear instructional objectives in like designing a product without a clear set of design specifications".

A document which is very often referred to in literature relating to experiment design in general is the outcomes of the 2002 ABET Colloquy which focused on laboratory education. (Lowe et al. 2012a) state that a key outcome of the discussions was a taxonomy defining thirteen diverse learning objectives for engineering laboratories. These objectives can be found in Appendix D of this document. The primary objectives relating to the experiment design are listed below:

Objective 1: Instrumentation – By completing laboratories in an undergraduate engineering curriculum the student should be able to apply appropriate sensors, instrumentation, and/or software tools to make measurements of physical quantities (Feisel & Rosa 2005).

Objective 2: Models – By completing laboratories in an undergraduate engineering curriculum the student should be able to identify the strengths and limitations of theoretical models as predictors of real-world behaviours. This may include evaluating whether a theory adequately describes a physical event and establishing or validating a relationship between measured data and underlying physical principles (Feisel & Rosa 2005) .

Objective 13: Sensory Awareness – By completing laboratories in an undergraduate engineering curriculum the student should be able to use the human senses to gather information and to make sound engineering judgements in formulating conclusions about real-world problems (Feisel & Rosa 2005).

Clearly these broad objective share a close correlation to the professional opinions and project goals of the MEC Course Examiner as outlined in Section 1.2. As a result, meeting these objectives will form primary design considerations for this project.

2.6 Applicable Australian Standards and Handbooks

Standards are published guidance documents which define quality and safety criteria for large range of products, services and systems. In Australia standards are developed, reviewed and promoted by Standards Australia, a non-government organisation. Australian Standards are not legal documents; however they are often referred to in government legislation and therefore become mandatory.

A number of standards are considered applicable to the design process of this project. These cover critical aspects such as safety through to considerations for ergonomics in design. Compliance with all appropriate Australian Standards in the design of this laboratory equipment will ensure the completed equipment is of a standard considered to be in-line with current best practice. Standards and Handbooks considered applicable to this project are summarised in the following subsections.

2.6.1 SAA HB 59-1994: Ergonomics - The human factor

This handbook is intended as a basic guide to the subject of ergonomics. Ergonomics is a design philosophy which studies the interactions between people, the equipment they use and the environment within which they are placed (StandardsAustralia 1994). The document encompasses a practical approach to work systems design based on these principles. SAA HB 59-1994 covers many topics valuable to the design phase of this project. Primary relevant sections include *human physical capabilities* and *physiological factors*.

2.6.2 AS 3590-1990 Screen-based workstations

This standard covers a number of topics particularly useful for overall design of the experiment frame including suitable heights, visual fields and important safety considerations. StandardsAustralia (1990) indicate that a standing workstation should be approximately 950mm in height if fixed or be in the range of 900mm to 1100mm if adjustable. In terms of safety, the Standard suggests that electrically operated workstations must comply with AS 3100. In addition workstations should be free from any sharp edges, corners, protrusions or rough surfaces and moving parts should not create hazards such as pinch or shear points (StandardsAustralia 1990).

2.6.3 AS 4024-2006: Safety of machinery

This large and comprehensive guide to ensuring the safety of all machinery is particularly relevant to the design and implementation of the proposed equipment. AS 4024-2006 is a series formed by a large number of individual Standards covering a broad range of machinery safety topics. Topics include the design of interlocks and guards and principles of risk assessments. Strict adherence with this Standard throughout the project's design phase will be critical to identifying and eliminating or any unacceptable potential risks to future equipment users.

2.7 MEC2402 Course Study Materials

MEC2402 Stress Analysis has two primary items of reference literature, a USQ published study book written specifically for the course and a commercially available text book which covers all course topics as detailed in Section 1.3.

Ensuring an appropriate correlation between theoretically predicted results and those witnessed in reality on the completed experiments is a primary goal of this undertaking. As such, careful analysis of the theory contained in the MEC2402 course materials will be vital to establishing these predicted results. The following two subsections provide an overview of the topics covered in these documents which specifically relate to the proposed experiments.

2.7.1 MEC2402 Stress Analysis – Study Book

The Study Book provided to students undertaking Stress Analysis forms a comprehensive guide to the subject. The document is separated into eleven chapters (or modules) covering all aspects of the course. While each of these modules has an element of relevance to the design of the proposed RAL apparatus the following are considered of primary importance:

- Module 1 – Normal Stress and Strain
- Module 3 – Shear Stress and Strain
- Module 4 – Torsion Members
- Module 5 – Stress Analysis
- Module 6 – Strain Analysis
- Module 8 – Normal Stress in Beams

Whilst in some instances the MEC2402 Study Book acts as a stand-alone teaching resource, students are frequently directed to sections of the text book where the majority of concepts are presented and developed.

2.7.2 Mechanics of Materials – Beer & Johnston (2009)

USQ (2013) indicates that Mechanics of Materials written by Beer and Johnston (2009) is the current textbook reference for MEC2402. The publisher of the text, McGraw-Hill (2013), clearly states that they consider the textbook is the undisputed global leader for the teaching of solid mechanics. The book is separated into 12 Chapters often sharing similarities to the MEC2402 Study Book Modules. All topics relating to experimental theory required in this project are comprehensively introduction, detailed and explored in this resource.

2.8 Conclusions

This chapter has successfully investigated a broad range of available literature relating to the implementation of laboratories in engineering education. Overall it appears apparent that the integration of a series of remote access experiments into *Stress Analysis* has a strong potential to be advantageous to student learning outcomes in the course.

By firstly analysing the history and background of engineering education it became clear that the style of engineering training has evolved greatly in recent times. Despite the highly practical nature of early engineering training, a situation is widely recognised to exist in which many of today's engineers graduate rich in theoretical knowledge yet poor in practical understanding. It was demonstrated however, by authors such as King (2008) and Kostulski and Murray (2010) that there is currently strong intentions amongst educators to move towards correcting these issues.

In addition it was shown that an important current trend in laboratory education is towards the use of remote labs and simulations in place of traditional hands-on experiments. Feisel and Rosa (2005) among others suggest that this move was primarily driven by the introduction of systems of distance education around the world. It was shown in Section 2.3 that while there is almost unanimous support amongst authors for the use of physical hands-on experiments there is widespread disagreement about using these new technologies in laboratory design. This topic was further explored in Section 2.4, where it was concluded that the proposed physical remote access lab has a large number of advantages over the use of computer simulations as a potential project solution.

Section 2.5 explored a number of issues relating to remote access laboratories specifically, and found that it is an area of much research interest and global growth. Despite a number of authors flagging the need for further conclusive research on the topic, authors such as Sonnenwald, Whitton and Maglaughlin (2003) and Corter et al. (2007) concluded that remote labs are just as effective as traditional hands-on labs.

In conclusion it appears clear that there is an enormous amount of support for the use of laboratories in technically based degree programs such as engineering. Whilst a shortage of technical literature relating to the physical design of remote labs has been identified, it is believed that careful consideration of a number of factors referred to in this chapter will ensure a positive design outcome for this project.

Chapter 3

Project Methodology

3.1 Chapter Overview

The following chapter provides the reader with a comprehensive understanding of the methodology implemented to ensure achievement of successful project outcomes. It is seen as important to firstly establish the design process which shall be applied before detailing the methods by which the manufacture of the generated designs shall be achieved. Following this, a summary of the testing and evaluation techniques to be applied to project outcomes shall be provided.

After establishing these fundamental requirements an evaluation of the consequential effects of this project shall be presented covering critical aspects such as safety, ethical and ecological issues. The outcomes of this section will in turn heavily influence the design, manufacture and evaluation of the proposed experiments. Finally this chapter covers an analysis of resources required for project completion as well as a project schedule.

3.2 Design Methodology

> *"Engineering problems are under-defined; there are many solutions, good, bad and indifferent. The art is to arrive at a good solution. This is a creative activity, involving imagination, intuition and deliberate choice."* - *Ove Arup*

The design methodology for this research project defines the process employed to take the proposed experimental apparatus as presented in Chapter 1 and achieve a successful final design outcome. Due to the complexity of this undertaking a clearly defined plan is seen as essential to achieving this outcome. It is important to firstly affirm that while many of the design decisions presented in the following chapters will be deliberate choices based on the results of analytical methods others will be based on design intuition alone. Ertas and Jones (1996) state that properly applying the correct balance between the use of intuition and more structured methods ensures the best design outcomes.

Most authors recognise the importance of intuition in developing innovative solutions to design tasks especially during the concept formulation stage. Design by intuition does not involve any formally presented analysis, concepts are instead synthesized into solutions by combining elements of relevant prior experience (Ertas & Jones 1996). In contrast, analytic methods of design are much more scientific in nature and involve following a well-defined process of design. This approach is seen as particularly valuable once concepts or potential solutions have been defined.

Material presented by Ertas and Jones (1996) in their book *The Engineering Design Process* will provide the basis for much of the design methodology of this project. Figure 2.1 outlines the typical steps in the engineering design process for a generic project of significant complexity. It is recognised that not all steps will be applicable to this particular project. Relevant steps will be further discussed following figure presentation.

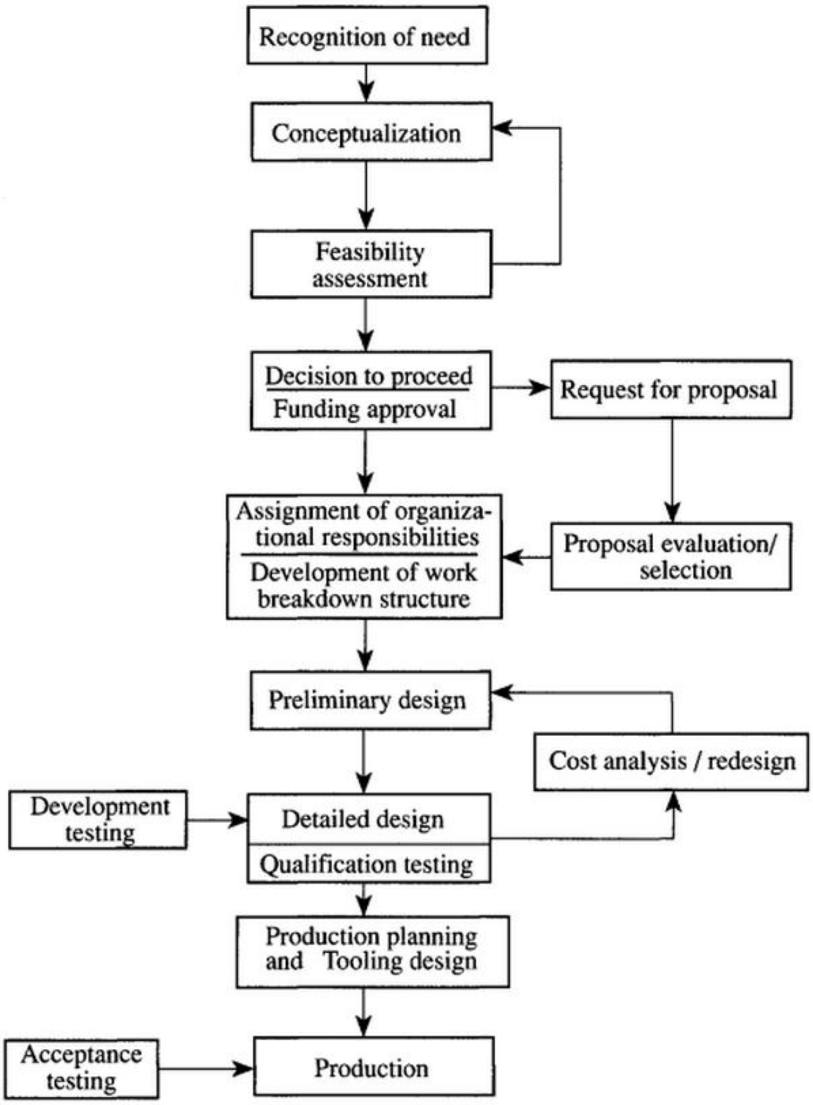


Figure 3.1 - Steps in the engineering design process (Ertas & Jones 1996)

As Figure 2.1 demonstrates, the design process begins with recognition of need and ends with the production of the item. The initial chapters of this document have already defined a number of these steps, primarily the recognition of need as a result of both the Course Examiners proposal in Chapter 1 and the justification for the use of laboratories in Chapter 2. It is considered from this point that the next stage of the design process is to commence the preliminary and detailed design. Section 3.3 deals with the manufacture methodology which shall be applied to the final production of the proposed apparatus based on these designs.

3.2.1 Primary Design Objectives

Subsection 1.4.4 of this document detailed some major design objectives of this project. These objectives define key requirements of the final apparatus design. These are numbered below:

1) **Comply with limited overall physical dimensions**
2) **Design for ease of transport**
3) **Ensure a strong correlation between physical results and theory**
4) **Achieve high quality results within provided budget.**

Prior to the commencement of the actual design process it is seen as important to formally establish and detail all remaining design objectives which will influence this project. These will form a vital framework for achieving successful project outcomes. It is important to note that all design objectives have been numbered arbitrarily. The remaining design objectives are numbered and described below:

5) **Design experiments to ensure appreciable visual results**

   Experiments should feature clearly visible deflections whilst under load. This is to help ensure the design complies with Objective 13 (sensory awareness) of the 2002 ABET colloquy as detailed in Subsection 2.5.4. Essentially a student should be able to use their human senses to gather information and make judgment about a situation. Despite the fact that highly accurate measuring equipment could be used to provide digital feedback of minute deflections, experiments should be designed to maximise this deflection to levels clearly apparent to the human eye.

6) **Provide all users with a very high level of safety**

   The use a remote access apparatus will be extremely safe for remote users. However the completed apparatus will also be used locally by staff and a significant number of on-campus students. As such, ensuring the design of all aspects of the experiments considers the possible safety implications will be absolutely vital. This is supported by the Course Examiner, (refer to Section 1.2) who suggested that 'safety' was the number one design criteria for successful laboratory integration into MEC2402. Section 3.5 of this report further explores potential apparatus safety issues.

7) Design experiments which appear familiar to students

The experiments should be designed so that students can focus on relevant course concepts. This involves attempting to design the appearance of the experiments in a manner similar to how problems are presented in course learning material. It is considered that attempting to replicate 'real' industrial style engineering systems on a laboratory scale would only serve to cloud a student's perception of the relationship between the theory and reality of Stress Analysis concepts. Similarly the experiments should not be designed to focus a student's attention on the use of automation equipment or remote access technology. As such this project aims to produce experiments which appear familiar to students and are easy to understand. The goal is to make the concepts appear as elementary and unintimidating as possible. Figure 2.2 and 2.3 are indicative of the style in which problems are presented in the course text book, *Mechanics of Materials* by Beer and Johnston (2009).

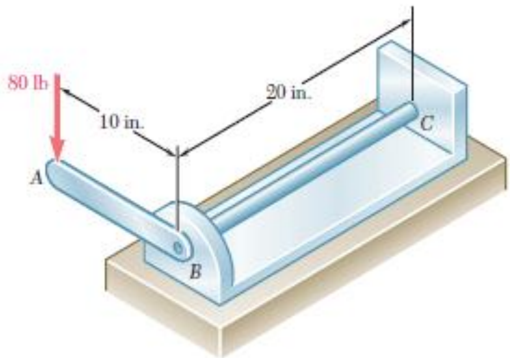


Figure 3.2 - Torsion problem from course text book (Beer & Johnston 2009)

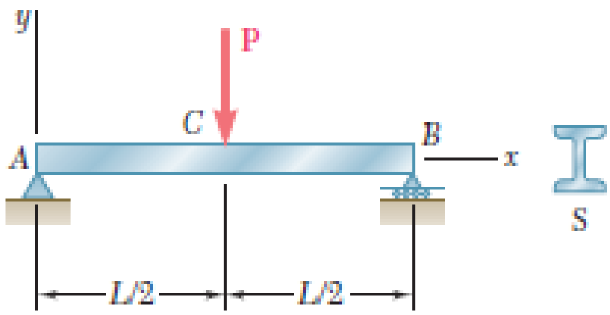


Figure 3.3 - Beam bending problem from course text book (Beer & Johnston 2009)

Producing experiments which replicate the simplicity of these systems will allow students to form a direct link between what they have studied in the course material and how this might relate to a real life system. Clearly this will ensure achievement of the Course Examiners goal to provide this connection to students.

8) Aim to ensure students trust the authenticity of results

Following the detailed discussion in Chapter 2, it was determined that creating physical laboratory experiments was the only way to impart a sense of the real world to students. The conclusion was drawn that creating simulations of the proposed experiments would not serve to reinforce student understanding but merely graphically depict the text book theory. Considering the proposed apparatus is to be a physical, remote access piece of equipment, care should be taken to ensure students 'believe' that the results are generated independent of theoretical calculations.

For example, loads will be applied to experimental systems through the use of linear actuators. By analysing the electrical input to these pieces of automation hardware, it is possible to accurately determine the displacement (deflection) and magnitude of any load being applied (Bowtell 2013). This data could then be output to the computer interface for students to record. However, why would a student trust these results any more than a text book theory? The experiments should instead, independently assess results through the use of sensory equipment such as load cells for weight and ultrasonic sensors for deflection. These tools should be in addition to the use of traditional visual measurement aids.

9) Experiments should involve materials commonly used in industry

The ultimate aim of this project is to provide students with a sense of how *Stress Analysis* theory relates to the real world. It was shown in chapter 2 that Edward (2002) suggests that the majority of engineering students expect to find employment in industry rather than as researchers. As such, it seems appropriate to integrate only real world materials into each of the experiments.

Whilst the majority of the theories presented in *Stress Analysis* are unaffected by material type, metals are seen as being highly relevant to students and future engineers. Commonly used metals include steel and aluminium. It is considered that most engineering students will be highly familiar with these materials.

Many authors including Juvinall and Marshek (2005) suggest that steel is the most extensively used metal for structures and machine components. All steels are said to have essentially the same modulus of elasticity (E), typically reported to be equal to 200 GPa. The validity of this statement is however, not currently demonstrated at any time during an undergraduate engineering degree at USQ. It is therefore clear that students will encounter optimised educational outcomes through technical investigation of this material.

Aluminium is also a widely used engineering material which would offer significant benefits to this apparatus through its use on any of the three experiments. Aluminium has relatively low values for its modulus of elasticity and modulus of rigidity when compared to other common metals. As such aluminium will typically exhibit larger deflections and for a given load. This will clearly assist in the fulfilment of primary design objective number five of designing experiments to ensure appreciable visual results. Further discussion with regards to material selection is included in Chapter 4 of this document.

10) Produce an aesthetically effective design

Considering this project, once completed, has the potential to be subjected to significant public exposure, it is seen of importance to ensure the visual appearance of the apparatus serves to reinforce the quality of the USQ brand. Producing a remote laboratory apparatus which appears of low quality (regardless of performance) would clearly be a poor final result for this project. Whilst achievement of this design ambition is rather subjective to assess, so too is the use of intuition in design to generate quality solutions. As a result, final achievement of this objective has been assessed in a similar manner.

3.2.2 Design Subsystems

In order to commence design work in the following chapter it is first essentially to separate the proposed design into a series of subsystems. The numbering of each of these subsystems will later define the order of design progression. Design subsystems are numbered and described below.

Design Subsystem 1 – Frame

This will involve the design of a suitable 'base' on which to mount the three proposed experiments, fit the touch-screen computer and safely house the electrical wiring and hardware. As per the requirements presented in section 1.4.4 the apparatus must fit within limited dimensions and be easily transportable. A critical outcome of the design of this subsystem is that it will define the area available for the three experiments. Preliminary experimental calculation will therefore be performed to ensure the appropriateness of the proposed experimental dimensions.

Once the frame design is finalised and the area available for mounting the three experiments has been set, the design of each of the three experiments can progress. The specifics of how the experiments apply and demonstrate the relevant theories will form the initial design work in each case.

Design Subsystem 2 - Shaft Torsion Experiment

Design of this experiment involves generating a MATLAB script which receives a number of relevant variables as inputs. Inputs include material properties, shaft diameter and shaft length. Script outputs include the maximum torque that can be applied to the shaft and the corresponding angle of twist. This data will then be analysed in order to select an appropriate material, diameter of shaft and a maximum level of shear stress which can be induced in the shaft. The design process for this experiment will also involve selection of a strain gauge rosette which will provide students with the opportunity to compare the values of theoretical and actual strain/stress.

Design Subsystem 3 - Unsymmetric Bending Experiment

The theory behind this experiment is the most complex of the three. The process of creating a design will again involve a MATLAB script capable of simulating the theoretical results of conducting an experiment. This will then be used to select the material and unequal angle profile which provides appreciable deflections and successfully concept demonstration. Specification of the maximum loading scenarios will also form a key outcome of this subsystem.

Design Subsystem 4 - Normal Stress in Beams Experiment

Creation of a MATLAB simulation of this experiment will allow for the direct comparison between a range of materials and cross-sections and permit an informed experiment design. The objective of this experiment is to demonstrate appreciable maximum material deflection with reasonably small load applications (less than 500 N). As with Experiment One, this experiment will also involve the preliminary selection of strain gauges to measure actual induced stress during experimentation.

Design Subsystem 5 - Guarding – The final design subsystem involves the detailing of a polycarbonate (or similar) cover which will enclose all experiments during use and ensure ultimate user safety. Design work will centre on material selection and geometry.

3.3 Manufacturing Methodology

Production of components will be commenced on completion of each design subsystem and as funds become available. Mechanical manufacturing and assembly of this project will be primarily achieved by the author and through the use of specialised contractors as required. Whilst detailing manufacturing aspects are considered largely beyond the scope of this research project, they remain critical to the successful completion of the project as a whole. As such the design phase of this project must heavily consider the availability of skills, techniques and processes in order to ensure the manufacturability of the designs and minimisation of costs.

Ertas and Jones (1996) clearly state the importance of consideration for the manufacturing and assembly of products during the design phase. Aspects of manufacturing which must be well understood during the design phase include material selection, handling and processing, quality control, when to specify purchased components and assembly.

3.3.1 Communication between Designer and Manufacturer

In order to obtain successful results from the production of components, all manufacturers will be provided with detailed technical drawings complying with AS 1100. Appendix I contains all technical drawings completed as a result of this project. Production of drawings to the appropriate Australian Standard (AS 1100) will ensure clear and efficient communication of design intentions between designer and manufacturer.

3.4 Testing and Evaluation Methodology

Testing and evaluation performed as part of this project will occur at variety of stages both to assist the design process and form valuable conclusions about final project outcomes. Testing and evaluation will be regularly performed following the completion of any manufacturing work to ensure the quality of delivered goods. Evaluation will also serve to assess how the physical components relate to the original design ambition. Concept testing will be performed on Design Subsystems 2, 3 and 4 (refer to section 3.2.2) to ensure each of the three experiments behave in a manner similar to theoretical calculations. Once design work is complete, evaluation of the overall physical apparatus will be performed to assess the achievement of all primary design objectives. The pedagogical merit of the operating apparatus shall be ultimately assessed via the results of a proposed user perception survey detailed in subsection 3.4.3.

3.4.1 Testing and Evaluation of manufactured components

Assessments will be regularly performed during the manufacturing of project components to ensure the achievement of the expected high standards. Considering the design work for various sub-systems will be achieved exclusively through the use of reference material or designer intuition it will be important to assess the quality and characteristics of the completed goods to determine whether design ambitions are being achieved. This style of continual review will ensure any major unforeseen issues can be resolved before further manufacturing work continues. Primary aspects of manufactured components to be analysed will include dimensional accuracy and usability. Results of this process are not included in this document.

3.4.2 Analysis of Experimental Concepts

Prior to specifying final designs for the three experimental subsystems, this project aims to assess whether each of the experiments can be designed and manufactured on a small scale to provide results which share a strong correlation to theory presented in MEC2402. This process will ensure achievement of project research objective B as outlined in Section 1.7. In addition, data generated from this testing and evaluation will be used for the later calibration of automation hardware. Testing methodology for the three experiments will vary significantly. Preliminary details relating to each subsystem are provided below:

Shaft Torsion Experiment
Suggested testing and evaluation includes accurately establishing the rate of shear strain for a given torsional load using the actual piece of material intended to be used on the experiment. The test apparatus will employ a combination of free hanging masses and accurate measuring equipment to manually obtain required results.

Unsymmetric Bending Experiment

Having the most complex theory of all three experiments the Unsymmetric Bending Experiment will require detailed concept testing prior to final manufacture. Tests will be specifically required to ensure the accuracy of the MATLAB simulations created to model the behaviour of the system. This will involve the application of bending moments to an unequal angle beam at a selected orientation. Producing a system which provides physical results with a strong correlation to complex *Stress Analysis* theory will dramatically improve the pedagogical merit of this experiment.

Normal Stress in Beams Experiment

Concept testing of this experiment will share similarities to the Shaft Torsion Experiment. The primary testing requirements will be to manually determine and record the actual beams response to the application of known loading conditions.

3.4.3 Final Testing and Evaluation

Final project testing and evaluation will be carried out prior to thesis submission and be based on the analysis of the finalised design work and any manufactured components. Given the subjective nature of many of the ten primary design objectives detailed in section 3.2.1, attainment of certain targets may be difficult to formally assess. This document will attempt to independently evaluate these outcomes.

Evidently, the proposed remote laboratory experiments will not be completed and integrated into *Stress Analysis* during the timeframe of this research project. As a result, final evaluation of the pedagogical benefit of the experiments must be performed following the submission of this dissertation. It is suggested that a user perception survey be included in the computer interface of the final apparatus. Programming this survey to appear on screen after students have used the experiments would provide an excellent opportunity to assess the impact of student's educational outcomes. Details of a proposed user perception survey are included in Appendix E.

3.5 Consequential Effects

The following section evaluates potential issues which may arise as a result of undertaking this project. The assessment will focus specifically on safety, ecological and ethical issues and attempt to identify areas of latent concern and take steps to mitigate potential harm.

3.5.1 Safety Issues

Safety has always played a role in the work of engineers however increasing emphasis is now placed on the subject. In the past engineers typically gave first consideration to the functional and economic aspects of creating a new product. In contrast, safety is now the subject of increasing engineering effort and a key consideration of successful engineering design (Juvinall & Marshek 2005).

Whilst safety is of substantial concern to legislators and attorneys, their role is purely to emphasise and enforce the importance of the safety in the development of engineered products. Engineers are however responsible for actually providing the community with safe products. Engineers must therefore be capable of identifying hazards associated with their designs and to quantify the relative severity and likelihood of occurrence.

Juvinall and Marshek (2005) assert that safety is inherently a relative matter requiring judgements to be made regarding trade-offs between safety, cost and weight amongst other factors. Clearly this project has the potential to be affected by a large number of safety issues. As such a comprehensive project risk assessment must be performed prior to commencing any design or construction work. Outcomes of this risk assessment will then act as a valuable reference source for the design process presented in Chapter 4. The risk assessment is divided into two separate dimensions:

1. **Risks involved during the execution of the project**. This will particularly pertain to the design, manufacturing and physical assembly and commissioning of the apparatus. Clearly a large number of hazards will exist during this phase, performing a comprehensive risk assessment will help eliminate these hazards or lower the likelihood of occurrence to acceptable levels.

2. **Risk involved beyond the completion of the project**. Considering the intention to implement the physical outcome of this project into USQ courses in future years, a critical aspect of the final design will be to ensure on-going staff and student safety. Conducting a risk assessment into this phase of the apparatus life cycle prior to commencing design work will assist in eliminating sources of potential future harm.

The risk assessment process for this project consists of firstly using a USQ hazard checklist to assist in the identification of all potential hazards associated with the proposed RAL experimental apparatus. This process involves recognising the possibility for the occurrence of generic safety issues. Answering affirmatively to any of the hazards stipulates the need to implement appropriate control measures to either minimise the **hazard** or lower the associated **risk**.

To summarise, risk arises due to the existence of hazards where:
A **hazard** is a source of physical harm.
A **risk** is the likelihood of harm occurring.

Following identification in the hazard checklist, individual processes are documented with their associated hazards noted. Existing controls are then summarised before a risk rating is calculated. This is then subject to an 'ALARP' (as low as reasonably possible) query to ascertain whether the existing controls and associated risk rating is acceptable or if additional controls are needed. Where required, additional controls are suggested followed by the calculation of an updated risk rating and ALARP review. All identified control measures must be implemented and/or included during completion of this project.

Selection of additional hazard/risk control measures for this project has been based on the hierarchy of design published by the National Safety Council (USA) This document sets the order of design priority for designing products to minimise injury. The hierarchy order is as follows (Krieger & Montgomery 1992):

1. Design to eliminate and minimise risk
2. Incorporate safety devices
3. Provide warning devices
4. Develop and implement safe operating procedures and employee safe training programs
5. Use personal protective equipment (PPE)

Complete details of the risk assessment process conducted for this assignment are contained in Appendix G and H. The primary conclusions affecting the apparatus design are summarised below:

- Include an appropriate handle on the frame to facilitate transportation and control of the apparatus.
- Design and select appropriate castors to provide a 'fixed' front end and a 'swivel and brake' rear end. This will ensure a high level of control during transport and minimise chance of uncontrolled movement.
- Design entire apparatus to have a large base of support and a centre of gravity as low as possible. This will minimise the possibility of tip-over.
- Installation of an interlock guarding system to ensure against accidental operation of experiments whilst the clear cover is removed.
- Installation of a mechanical lock and warning stickers to cabinets to protect users from contact with live electrical componentry.

Implementation of all identified control measures into the design process will ensure a high level of user safety. Achieving this objective will satisfy the requirements of Primary Design Objective number six, identified in section 3.2.1.

3.5.2 Ecological Considerations

EngineersAustralia (2010) specify that engineers are responsible for fostering the wellbeing of the environment. As such, this research project must appropriately consider ecological issues which relate the design, manufacture, operation and final disposal of the proposed experimental apparatus. Detailed below are a number of selected factors which are amongst those considered by Juvinall and Marshek (2005) to be of primary importance in minimising the ecological harm of engineering endeavours.

1. **Select ecologically sensible materials -** Important considerations should include the known natural availability of raw material and the energy requirements of material processing or manufacture. This also relates to the local availability of a material. Clearly minimising the distances from which a material must travel specifically to form a component of this project is an important ecological factor.

2. **Design for ease of replacement or updating of components –** This concept involves designing a product so that individual components can be easily replaced or modified without the need to completely replace the product. This will dramatically increase the life span of the overall apparatus which in turn offers significant ecological benefits through the minimised material and manufacturing energy usage.

3. **Design for durability and long working life –** Similar to the previous concept. A product should have the quality, robustness and durability of its design balanced against its expected life span to minimise the energy and material requirements. This is seen as a particularly important concept to minimising the ecological harm of this project.

4. **Select ecologically sensible manufacturing processes –** Important aspects include consideration for any directly generated pollution, energy consumption as well as the efficiency of material usage. Selection of appropriate manufacturing processes is similar to the selection of ecologically sensible materials in that they should also strongly consider local availability in order to minimise ecological harm associated with unnecessary product transport.

5. **Design for recycling or disposal –** Whilst not traditional an area of concern, it is becoming increasingly important for engineers and designers to consider the full ecological cycle and impact of their work. This complete cycle includes consideration for the eventual recycling or disposal of a product in addition to the manufacture and operation. Important factors include designing for ease of final dismantling and separation of recyclable materials.

3.5.3 Ethical Issues

> *"Ethics is a set of standards by which a particular group decides to regulate is behaviour – to distinguish between what is legitimate or acceptable in pursuit of their aims and what is not" (Flew 1999)*

EngineersAustralia (2010) provides a code of ethics which outlines a list of guidelines for engineering practice. These guidelines cover integrity, competence, leadership and sustainability. It is of significant importance to ensure that this code of ethics be upheld at all times during the undertaking of this project. Inspection of the Engineers Australia Code of Ethics reveals two primary guidelines which are heavily related to this particular research project. These are as follows:

Act on the basis of adequate knowledge – The final physical outcomes of this project are to be used for the educational benefit of future engineering students. As such it is important to ensure that all work carried out during this project is within the authors experience and in line with commonly accepted standards. This will strongly contribute towards ensuring high quality physical results and maximisation of potential pedagogical benefits. In accordance with EngineersAustralia (2010) and as part of this overall concept, the author also has a responsibility to inform the project supervision team if any aspects of the undertaking are outside of the areas of competence.

Practise engineering to foster the health, safety and wellbeing of the community and the environment – Whilst the majority of these aspects have been previously covered in this chapter, it is important to identify them as ethical obligations of the project. EngineersAustralia (2010) suggests that health, safety and environmental considerations, amongst others, must be included in engineering all tasks. Successful implementation of the outcomes of the project safety issues and ecological considerations will ensure compliance with this ethical guideline.

In addition to compliance with the Engineers Australia Code of Ethics this project requires additional USQ ethical clearance as detailed in Section 1.2. This relates to conducting the formal interview with the MEC2402 Course Examiner to establish his professional opinions regarding this project (refer to appendix B)

3.6 Project Resource Analysis

The resources requirements for this project must be divided into two distinct parts. The first of these involves the resource requirements of undertaking of this research project specifically. The second relates to the broader objective of actually manufacturing and delivering the complete proposed experimental apparatus.

3.6.1 Resource Requirements – Project Design and Evaluation

Resource requirements of this research project mainly involve computer software for design as well as measuring tools for evaluation of any manufactured components. Considering all of these resources are already owned by the author or readily available on the USQ computer network, availability is assured. Summary of the resources required to complete the design and evaluation phase of this project include:

- **Microsoft Word 2010 –** For document creation and presentation.
- **Microsoft Excel 2010 –** For initial analysis and comparison of results likely to be obtained through the use of certain materials and cross-sections in each experiment.
- **SolidWorks 2010 Premium –** For generation of 3D rendered models of both concept drawings and final design. The program will also be used to generate 2D fabrication drawings for inclusion in project and for reference during manufacture.
- **MATLAB R2011b –** For generating scripts which theoretically model the behaviour of the three proposed experiments. Outputs of this program shall then be used to draw comparisons between physically obtained results completed. This will form an important component of the testing and evaluation methodology for this report, as detailed in section 3.4.
- **Various engineering measurement tools –** This includes use of items such as a tape measure, steel rules and Vernier calipers to evaluate the geometry and dimensions of manufactured components.

3.6.2 Resource Requirements – Project Manufacture

The resources required to complete the final manufacture and commissioning of this project were preliminarily analysed at the commencement of this research project. This was completed in close collaboration with all project supervisors for the purpose of generating an estimated project budget. However considering the ambitious nature of this student project, specific details of all resource requirements is difficult to confirm. A preliminary summary of the requirements is provided below:

- **Metal fabrication facilities and skilled labour –** For fabrication of the frame, experiment mounts and the experiment bases.
- **Metal machining facilities and skilled labour –** For creating any machined components which cannot be readily purchased from suppliers.
- **Joinery –** For sheeting the frame with appropriate materials.
- **Touch screen computer –** To be purchased and fitted to frame to control experiments and provide interface for experimental activities.
- **Automation hardware –** To be purchased from suppliers. Items will likely include linear and rotary actuators used to physically manipulate experiments.
- **Sensory equipment –** To be purchased from suppliers. Items will likely include cameras, ultrasonic sensors and load cells to provide users will feedback of experimental results.
- **Plastic fabrication facilities and skilled labour –** For custom-making of the proposed clear plastic cover over the 3 experiments.
- **Electrical design / installation facilities and licenced labour –** For completing electrical design and installation work once physical apparatus is completed. Note: This is outside of the project scope.
- **Interface design –** For programming of user control interface. Note: This is outside of the project scope.
- **Metal coating facilities –** For application of protective coatings to the metal items such as the frame and experiment base.
- **Miscellaneous hardware supply –** Such as any required fasteners or similar.

Successful completion of this project as per the project specification (refer to Appendix A) requires a significant financial input by USQ. The availability of this funding with respect to research project timelines will heavily influence the obtainability of manufacturing and specific testing objectives identified in the project specification. Appendix F contains details of the achieved project schedule with respect to funding. Specifics of project financial requirements have not been included in this document

3.7 Project Schedule

The project schedule description has been separated into two separate sections, namely the proposed and achieved project schedule (refer to Appendix F). The proposed project schedule covers the original project timelines that were predicted before commencement of project work. Alternatively the achieved schedule refers to the actual timeline that was realised during project completion.

Comparison between these timelines will later assist in forming valuable conclusions about the effectiveness of the implemented project methodology. Inspection of project schedule details highlights that the achievement of project timelines was significantly different to the originally proposed schedule. This is contributed primarily to delays in the securing and availability of funding for the project. This is further discussed in Chapter 6 of this document.

3.8 Chapter Summary

This chapter has provided a comprehensive understanding of the methodology implemented to ensure achievement of successful project outcomes. Primary topics covered have included the design and manufacture methodologies, testing and evaluation methodologies and identification of the consequential effects. These effects included analysis of safety, ethical and ecological issues which may occur as a result of this project. In addition this chapter has also identified project resource requirements and evaluated the project schedule.

The design of the proposed experiments shall be achieved through a combination of intuition and analytic techniques. This was based on the assertion by Ertas and Jones (1996) that applying the correct balance between the use of intuition and more structured methods ensure the best design outcomes. Section 3.2.1 outlined a series of ten Primary Design Objectives which formally identify the factors seen as critical to achieving successful project outcomes. These also form a vital framework for later testing and evaluation.

Section 3.2.2 separated the proposed design into a series of five design subsystems which define the boundaries and logical progression of individual design tasks. These subsystems included:

1) Frame
2) Shaft Torsion Experiment
3) Unsymmetric Bending Experiment
4) Normal Stress in Beams Experiment
5) Guarding

The manufacturing methodology outlined in Section 3.3 established that the manufacturing aspects of the project are seen as largely outside the scope of this document. Despite this exclusion, it was recognised that consideration for manufacturing aspects will form a vital component of the design phase of this project. Important aspects include the availability of skills, techniques and processes in order to ensure the manufacturability of the designs and minimisation of costs. Manufacturing of the proposed apparatus in accordance with the outcomes of design process will be based on preparation of appropriate technical drawings.

Testing and evaluation will occur at a variety of stages throughout this project in several key areas. These include testing and evaluation of manufactured components, evaluation of experimental concepts and final apparatus testing and evaluation. The results of this analysis will be used to form valuable conclusions about project outcomes.

Section 3.5 identified a number of important consequential effects of undertaking this project. Subsection 3.5.1 investigated relevant safety issues resulting in a series of design requirements necessary to minimise the risk of this project during and after completion. Subsection 3.5.2 investigated ecological considerations which should be taken into account during the design process to minimise any potential ecological harm. Subsection 3.5.3 explored ethical issues relating to the project and identified relevant ethical guidelines provided by the Engineers Australia Code of Ethics. Implementation of all recommendations proposed in this section will ensure minimisation or elimination of any foreseeable adverse project outcomes.

The project resource analysis was detailed in section 3.6. Project resource requirements were divided into those necessary during project design and evaluation and those required during project manufacture. Limited resources are required during the design and evaluation phase as such these will be provided to the project by the author. The manufacturing phase will require a significant resource input, to be supplied through funding from USQ. The final section 3.7 of this chapter discussed details of the project schedule, both proposed and achieved. Final conclusions regarding the project schedule will be discussed in Chapter 6 of this document.

Chapter 4

The Design Process

4.1 Chapter Overview

This chapter aims to complete the design of the proposed experiments through careful consideration of the material presented in the previous three chapters. This task has been divided into five separate design subsections as per details presented in Subsection 3.2.2. Individual design subsystems are:

1) Frame
2) Shaft Torsion Experiment
3) Unsymmetric Bending Experiment
4) Normal Stress in Beams Experiment
5) Guarding

Chapter 1 of this document provided an introduction to this project and briefly described the proposed experiments. Chapter 2 investigated relevant literature relating to laboratory education in engineering education. Finally, a large number of design requirements were identified in Chapter 3 which explored the specifics of the project methodology. The present chapter - *The Design Process* - seeks to effectively integrate all important aspects of this previous work and ultimately produce technical drawings of proposed designs. This chapter is presented in a functional style.

4.2 Frame Design

The frame subsystem involves the design of a suitable 'base' to mount the three proposed experiments, fit the touch-screen computer and safely house the electrical wiring and hardware. Figure 4.1 depicts initial concept model of the frame which was created for the project funding application.

Figure 4.1 - Initial frame concept model

In this model it can be seen that the large flat surface to the right of the image is intended for the later installation of the three experiments. The electrical enclosure shown was arbitrarily selected based on its previous use on the USQ hydraulics RAL project. This project involved the commissioning of a series of five separate RAL apparatuses, completed in December 2011. Each apparatus used an electrical enclose (600x900x450mm) mounted at a height sufficient for a touch screen computer to be installed into the door around eye level (see Figure 4.2). The concept model for the frame instead located the enclosure underneath the bench top with the touch screen computer mounted into the upper surface facing upwards towards to users face. This was in order to maximise the users view of the experiments and keep the centre of gravity as low as possible to ensure stability. Four castors are shown on each lower corner of the frame to facilitate transport.

Figure 4.2 - Electrical enclosure and touch screen used on hydraulics RAL project

This section summarises and considers all previously identified requirements for the frame and generate a final design ready for manufacture. Inclusion of the initial concept model is only in order to provide the reader with some context for proposed frame. Final frame design will differ considerably from this concept.

4.2.1 Requirements of design

Chapters 1 through 3 of this document identified a significant number of requirements which should be considered frame design. These are summarised below. The Frame should:

- Comply with limited overall dimensions
- Be designed for ease of transport
    - Include an appropriate handle to facilitate control of apparatus during transport
    - Feature castors which are *fixed* on the front end and a *swivel and brake* on the rear end.
- Have a large base of support and a centre of gravity as low as possible
- Have a mechanical lock fitted to electrical enclosures.
- Be of high quality construction and designed for a long working life
- Be designed for recycling or disposal
- Use ecologically sensible materials
- Feature an attractive design
- Be free of any sharp edges, corners, protrusions or rough surfaces

4.2.2 Touch Screen Computer

The computer selected for use on this apparatus is the *Dell OptiPlex 9010 All-in-One* (touch screen model). This particular model is currently being used by USQ ICT and as such has been recommended for inclusion in this project. Being an 'All-in-One' implies that the entire computer is contained within the 'screen' and therefore no additional hardware is required for operation.

Figure 4.3 - Dell OptiPlex 9010 All-in-One computer (source: www.dell.com)

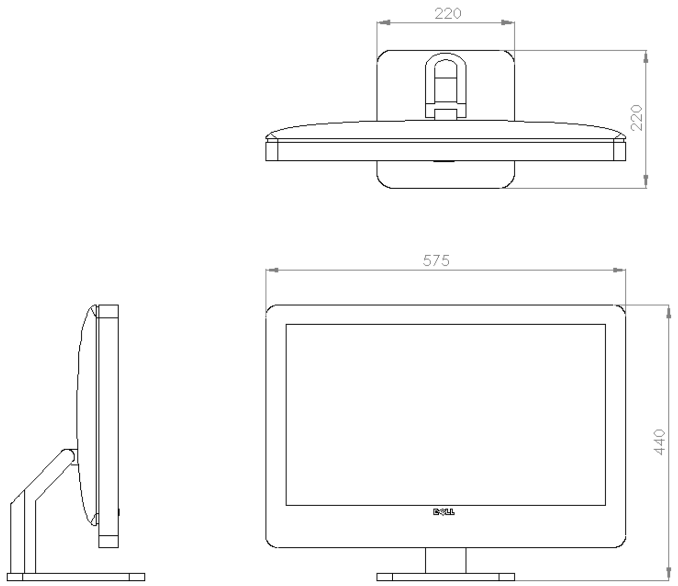


Figure 4.4 - Principal dimensions of Dell OptiPlex 9010 All-in-One

This computer is also available with an articulated stand which allows for significant angular manipulation of the screen about a horizontal axis. If available at the time of purchasing, this option would be highly desirable.

Figure 4.5 - Dell OptiPlex 9010 All-in-One with articulated base (source: www.dell.com)

4.2.3 General Dimensions

It was stated in Subsection 1.4.4 that the completed rig must be of a relatively small scale based on a desire to easily transport it around any USQ campus. As such the apparatus frame must be able to fit comfortably through standard doorways and into elevators. This is in accordance with the Course Examiners requirements. Primary dimensions finalised in this section will include the finished width, length, height of the apparatus.

Width

The width of the frame (transverse to direction of travel) is to be specified with consideration for the dimensions of standard public building doorways. Details of these dimensions will be based on AS 1428.1-2009 which outlines building design requirements for access and mobility. The standard indicates that the minimum clear opening of a doorway on a continuous accessible path of travel shall be 850 mm (StandardsAustralia 2009). Many standard doorways are however narrower than 850mm. This is likely in accordance with the Building Code of Australia (BCA) stipulation that no doorway shall be less than 750mm in width. This condition does not apply to doorways located in continuous accessible paths of travel (required for people with disabilities) as referred to by AS 1428. Based on this information the overall width of the frame shall be arbitrarily set at a value of 700mm.

Length

The length of the frame must to be appropriately specified to ensure sufficient space for the installation of the touch-screen computer and experiments whilst facilitating ease of transport. It is also essential that the frame be short enough to fit within USQ elevators.

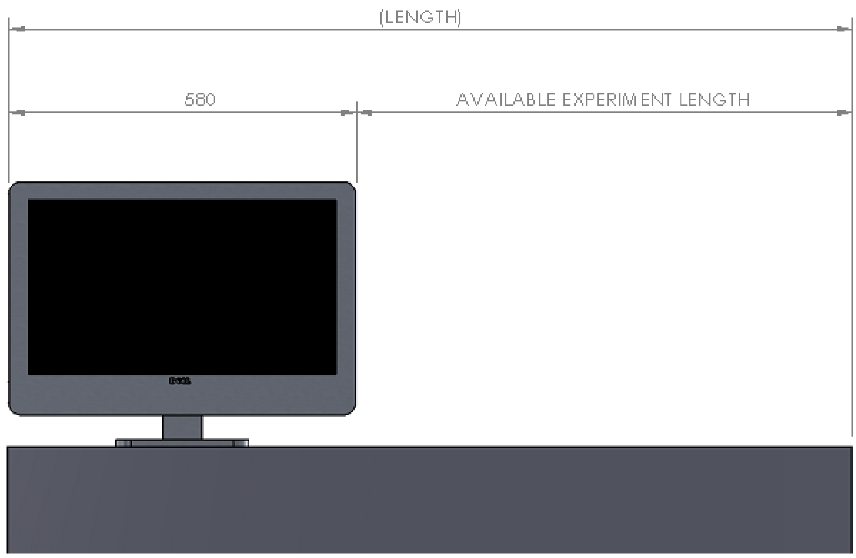


Figure 4.6 - Summary of available frame length dimensions

Investigation of selected elevators around USQ's Toowoomba campus has shown that the available dimensions are frequently in excess of 2000mm. The length of the frame shall therefore be set at 1400mm, a measurement equal to twice the frame width and seen to be aesthetically the most appropriate.

As is clearly shown in Figure 4.6, the length available for the three experiments will be equal to the frame length minus the approximate computer width of 580mm. This therefore leaves an 820mm maximum length for the experiments. The existing experimental rig from the 2013 offering of *Stress Analysis* was able to produce quality results using approximately 600mm of experimental length. As such, 1400mm is seen as an appropriate overall frame length.

Height

Subsection 2.6.2 of this document referred to details of AS 3590-1990 which specifies that the overall height of non-adjustable screen-based workstations for standing users should be approximately 950mm in height. A completed apparatus height of 930mm has therefore been selected. This value was designated slightly lower than the suggested height in order to provide some capacity for later installation of components which my slightly raise the overall frame height. Consideration for this dimension was also made in regards to ergonomic and anthropometric factors presented in SAA HB 59-1994.

In summary, following the brief analysis presented in the current section the finalised general dimensions for the apparatus include an overall width of 700mm, length of 1400mm and a height of 930mm.

4.2.4 Material Selection

The primary material selected for the fabrication of the frame is mild steel 40x40x2.5 mm square hollow section (SHS). This cross-section has been selected based on the authors experience in the design of fabricated structures. Furthermore, identical SHS section has been previously specified for similar USQ RAL experiments providing excellent results. The wall thickness of 2.5mm was selected as it is considered to be the lightest section suitable for frame fabrication.

Steel has been designated as the most appropriate material for a number of reasons. Primary reasons include the following properties:

- Strong, rigid and durable material
- High natural availability of raw materials
- High recyclability
- Material and fabrication expertise are locally available
- Can be easily modified after initial fabrication

Many of these factors were identified in section 3.5.2 – Ecological Considerations. Therefore, steel appears to be a justified material selection for frame fabrication. The only other material which may have offered a potential solution is aluminium. Although aluminium is significantly lighter than steel it was considered to have excessive fabrication costs and inadequate strength and rigidity for the task.

4.2.5 Proposed Design

Instead of the overall frame concept illustrated in Figure 4.1, it has been concluded that an alternative design would be beneficial. Rather than purchasing and installing a commercial electrical enclosure underneath the frame, all surfaces should be sheeted in an appropriate material with doors installed along one side. This concept will allow the entire frame to act as the electrical enclosure. Principal advantages include the opportunity for all electrical wiring to be easily connected directly to automation hardware on the upper surface of the frame.

As depicted in Figure 4.7 the proposed frame design includes a circular hollow section (CHS) handle across the entire width of one end of the frame. The handle is to be located on the end nearest the computer to enable close observation and support of the computer during transport. The handle shall be considered as a grab rail in accordance with AS 1428.1-2009. This standard indicates that grab rails shall not be less than 30mm nor more than 40 mm outside diameter. The clearance between the grab rail and any adjacent surface must be not less than 50 mm and not more than 60 mm. In addition the rail must be capable of withstanding a force of 1100 N applied at any position and in any direction.

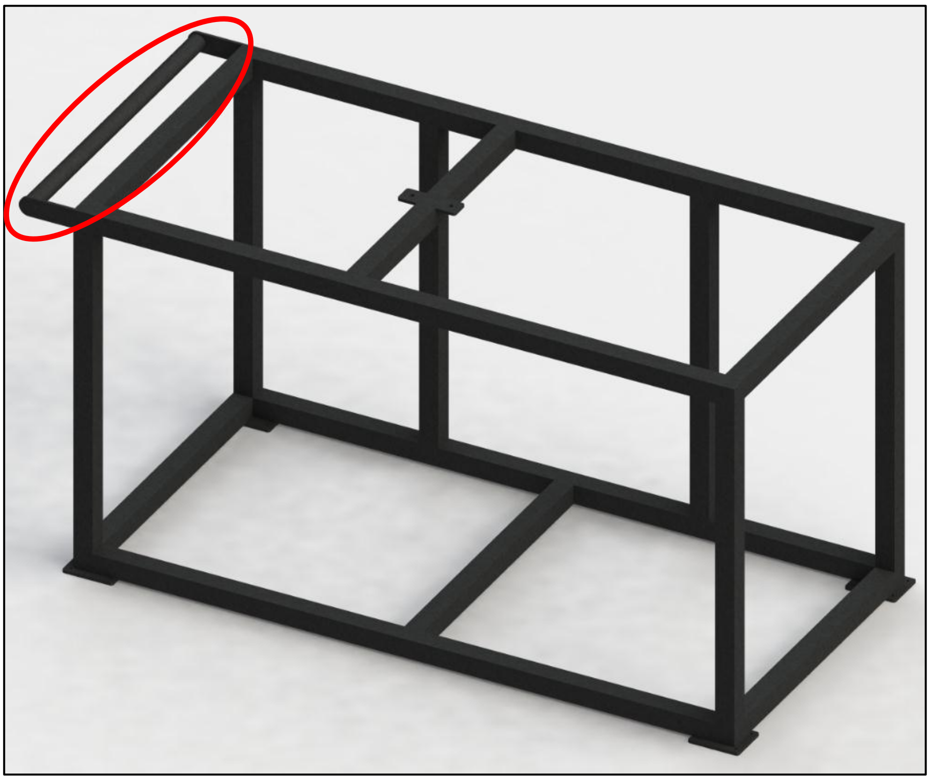


Figure 4.7 - Proposed hollow section steel frame

The frame is to be powder coated in satin black. Powder coating will provide an aesthetically desirably hard wearing finish which will ensure a long frame service life.

4.2.6 Castor Selection

As specified in section 3.5.1 the frame should be made transportable through the use of castors. These shall be ‘fixed’ one end and ‘swivel & brake’ the other. Figure 4.8 shown below depicts these different castor styles.

Figure 4.8 - Overview of specified castor types

Blackwoods (2013) provides excellent design advice with regards to castor selection. According to this source, primary aspects of appropriate castor selection include the load capacity and the choice of ‘tyre’ material. Load capacity is considered the most important of these factors. If the capacity of the castors is too low the castors may fail potential causing injury. Figure 4.9, taken from Blackwoods (2013), identifies the correct method for specifying load capacities of 4 wheel trolleys.

FOUR WHEEL TROLLEY

By far the most common style, four wheel trolleys are inherently stable. In general use, on a level floor and with an evenly distributed load on the trolley tray, each castor is loaded at 25% of the total load. However, when on an uneven floor, one castor may loose contact with the floor and the total load will carried by only 3 castors.

- Recommended Load Capacity per wheel = 35% of TOTAL LOAD (i.e. if TOTAL LOAD = 100kg, each wheel should have a minimum load capacity of 35kg

Figure 4.9 - Method of specifying the required load capacity of castors (Blackwoods 2013)

Considering the final design has at this point not been completed, the total apparatus mass is currently unknown. A conservative total mass has therefore, been assumed at 200 kg. In accordance with the procedure presented in Figure 4.9 the minimum required load capacity of each of the four castors will be as follow.

$$200\,kg \cdot 0.35 \quad = \quad 70\,kg$$

Selection of castor tyre material has been in accordance with information presented by Blackwoods (2009), shown in Figure 4.10. This resource compares all common materials and rates there performance in a number of key areas.

	Shock Absorbency	Capacity	Push Effort	Floor Protection	Durability	Typical Surfaces	Comments
Polyurethane	Good	Excellent	Good	Good	Good	All surfaces, irregular	Best all round choice
Grey Rubber	Excellent	Good	Fair	Excellent	Good	Quality flooring, quiet or clean areas	Good protection for floor & loads
Blue Rubber	Excellent	Good	Fair	Excellent	Good	Quality flooring, rougher surfaces	Highest shock absorbency
Black Rubber	Excellent	Good	Fair	Good	Fair	Industrial areas, concrete	Good shock protection on industrial floors
Pneumatic	Excellent	Fair	Poor	Excellent	Good	Outdoor, irregular or unsealed	Best over irregular surfaces. Highest resilience
Nylon	Fair	Excellent	Excellent	Fair	Good	Smooth concrete	Strong & economical. Can be noisy
Cast-Iron	Poor	Excellent	Excellent	Poor	Excellent	Oven floors, outdoors/ unsealed, broken glass	Strong and hard wearing. Best for high temperature. Will damage flooring

Figure 4.10 - Comparison of common castor tyre materials (Blackwoods 2009)

Following careful inspection of this figure the material seen as the most appropriate for this project is grey rubber. The excellent shock absorbency and floor protection were the primary reasons for this selection.

Having confirmed the load capacity and tyre material, final castor selection was then based solely on desired wheel diameter. Available wheel diameters of ‘grey rubber’ castors are shown in Figure 4.11. Blackwoods (2009) suggests that larger wheel diameter significantly lower the push effort required and a castors ability to negotiate obstacles.

Wheel Diameter mm	Wheel Width mm	Capacity kg	Castor Height mm	Plate Type	Fixed	Swivel	Swivel & Brake
80	32	60	110	A		**0683 2018**	**0683 2171**
80	32	60	110	C	**0683 2052**		
100	34	80	130	A		**0683 2035**	**0683 2137**
100	34	80	130	C	**0683 2069**		
125	37	105	152	A		**0683 2120**	
125	37	105	152	B			**0683 2290**
125	37	105	152	C	**0683 2256**		
150	40	145	192	B		**0683 2103**	**0683 2307**
150	40	145	192	D	**0683 2273**		

Figure 4.11 - Summary of castors available in grey rubber (Blackwoods 2009)

Clearly the 100mm wheel diameter option is the smallest castor to have a load capacity in excess of the required 70kg. These castors were therefore selected for use in this project. Appendix I contains specific castor details.

4.2.7 Joinery Specification

16mm thick Laminex™ sheeting was selected as the material with which to cover the SHS frame. This selection was made following advice from Clark (2013) who suggested the materials use for a number of reasons, these include:

- High local availability of material and processing capacity
- Ease of maintenance
- 16mm thickness will provide excellent rigidity over spans
- Relative low cost
- Renewability of the raw materials

Laminex™ sheeting is available in a large number range of colours (Laminex 2013). 'Charcoal' was selected by the author for a combination of aesthetic and practical reasons. Being a dark neutral colour will ensure ease of maintenance and will also provide a suitable background surface for which to affix any USQ branding if desired. A sample of Laminex™ Charcoal is shown in Figure 4.12.

Figure 4.12 - Colour selected for sheeting of frame – Laminex™ Charcoal

4.2.8 Analysis of proposed design

Prior to finalisation of the frame design it is seen a critical to examine two aspects of the proposed design. Firstly the serviceability of the frame material should be analysed specifically the horizontal span at the 'front' of the frame. Secondly the strength of the proposed handle must be analysed to ensure compliance with AS 1428.1-2008.

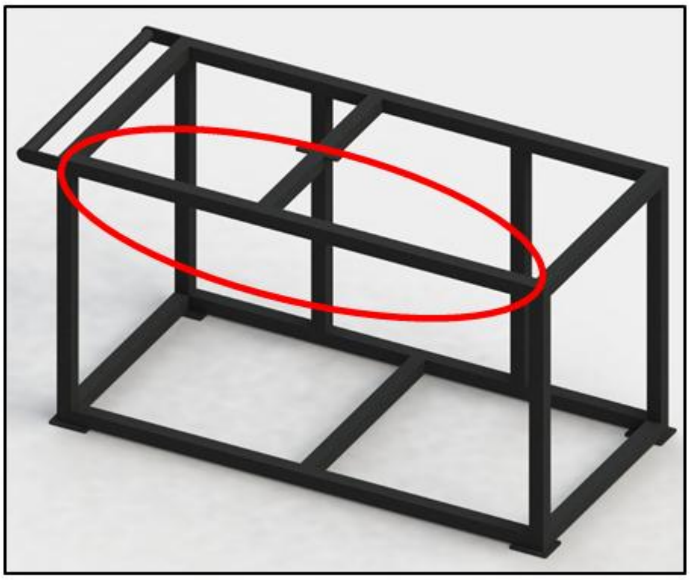


Figure 4.13 - Horizontal span of SHS to be analysed for serviceability

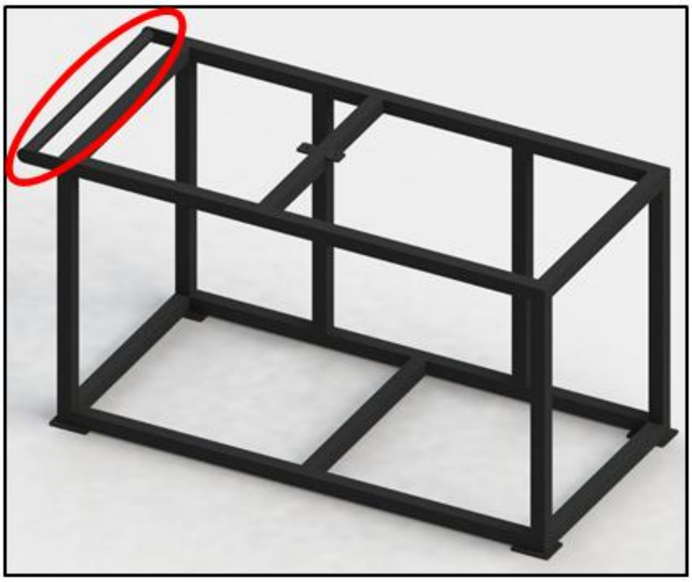


Figure 4.14 - Proposed handle design to be analysed

Horizontal span – The concern with this aspect of the design is that if the material experiences excessive deflection whilst loaded, the doors (to be located below) may jam. Figure 4.15 provides an overview of the span involved. Whilst the exact total apparatus mass is not currently known a conservative central point load of 100 kg shall be assumed.

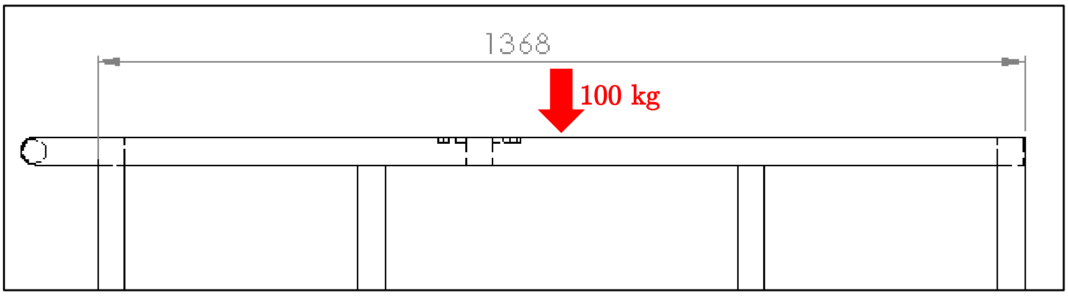


Figure 4.15 - Overview of SHS span to be analysed

In order for the 40x40x2.5 SHS to be considered as an appropriate material selection the maximum deflection (δ_{max}) over this span ($\approx 1320\,mm$) should as follows:

$$\boldsymbol{\delta_{max} = span \;/\; 500}$$

Therefore:

$$\boldsymbol{\delta_{max} = 1320 \;/\; 500}$$

$$\boldsymbol{\delta_{max} = 2.6\,mm}$$

The span shall be conservatively assumed to be simply supported to simplify calculations. OneSteel (2012) specifies the following technical data for 40x40x2.5 SHS:

$$\boldsymbol{I_x = 82.2 \times 10^3\,mm^4}$$

$$\boldsymbol{E = 200{,}000\,MPa}$$

The maximum deflection of a centrally loaded beam is theoretical calculated using the following formula:

$$\boldsymbol{\delta_{max} = \frac{PL^3}{48EI}}$$

Where:

$$\begin{aligned} \boldsymbol{P} &= 100\,kg \cdot g \\ &= 100\,kg \cdot 9.81\ m/s^2 \\ &= 981\,N \\ \boldsymbol{L} &= 1320\,mm \end{aligned}$$

Therefore:

$$\boldsymbol{\delta_{max}} = \frac{\boldsymbol{981\,N \cdot 1320mm^3}}{\boldsymbol{48 \cdot 200000\,MPa \cdot 82.2\ \times 10^3\ mm^4}}$$

$$\boldsymbol{\delta_{max}} = \frac{\boldsymbol{981\,N \cdot 1320mm^3}}{\boldsymbol{48 \cdot 200000\,MPa \cdot 82.2\ \times 10^3\ mm^4}}$$

$$\boldsymbol{\delta_{max}} = \boldsymbol{2.86\,mm}$$

Although this deflection is slightly in excess of the specified maximum it is considered appropriate due to the conservative assumptions made in the calculations. 40x40x2.5 SHS is therefore considered to be a suitable material selection.

Handle Strength – The capacity for the handle to support a load must be confirmed in order to ensure the compliance of the design with AS 1428.1-2008. This standard specifies that a grab rail must be able to support a load of 1100 N in any direction and at any point on the handle. This requirement was identified in Subsection 4.2.5. Figure 4.16 provides an overview of handle geometry and load placement. Two separate loading scenarios must be analysed:

1. Mid span loading of CHS (33.7 x 2.6mm CHS)
2. End of span loading of the flat mild steel 40 x 6mm FMS)

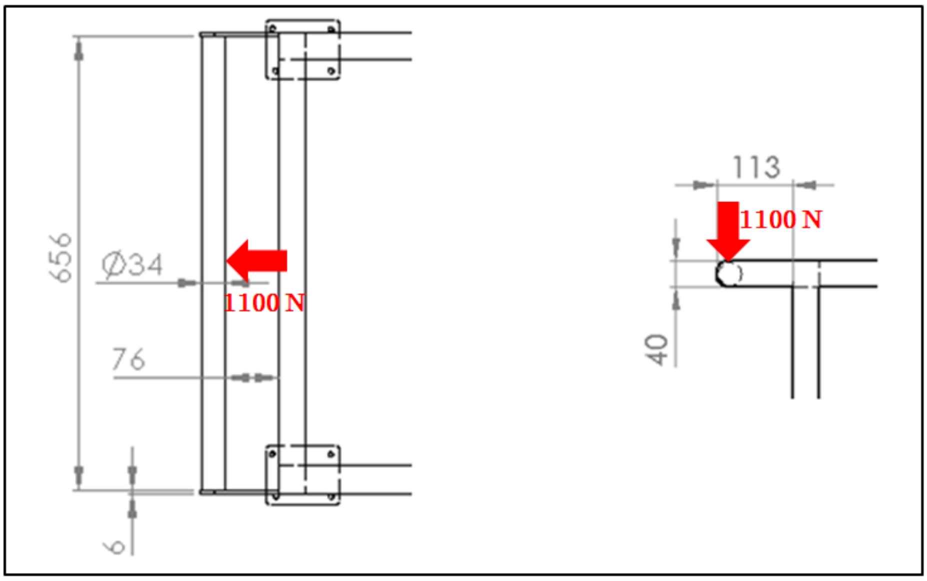


Figure 4.16 - Overview of handle geometry and loading scenarios

Scenario 1 – Check for normal stress in CHS using:

$$\boldsymbol{\sigma} = \frac{\boldsymbol{My}}{\boldsymbol{I}}$$

Where:

$$\boldsymbol{M} = 1100\,N \cdot \frac{656}{4} = 180400\,N \cdot mm$$

$$\boldsymbol{y} = \frac{33.7}{2} = 16.85\,mm$$

$$\boldsymbol{I} = 30.9 \times 10^3\,mm^4 \text{ (OneSteel 2012)}$$

Therefore:

$$\boldsymbol{\sigma} = \frac{\mathbf{180400}\,\boldsymbol{N \cdot mm \cdot} \mathbf{16.85}\,\boldsymbol{mm}}{\mathbf{30.9 \cdot 10^3}\,\boldsymbol{mm^4}}$$

$$\boldsymbol{\sigma} \approx \mathbf{98.5}\ \boldsymbol{MPa}$$

OneSteel (2012) indicates the yield stress of 33.7 x 2.6 CHS is 350 MPa. It is therefore clear that the proposed design is capable of withstanding loading scenario 1.

Scenario 2 – Check for normal stress in FMS using:

$$\boldsymbol{\sigma} = \frac{\boldsymbol{My}}{\boldsymbol{I}}$$

Where:

$$\boldsymbol{M} = 1100\,N \cdot 93\,mm = 102300\,N \cdot mm$$

$$\boldsymbol{y} = \frac{40}{2} = 20\,mm$$

$$\boldsymbol{I_y} = 32.0 \times 10^3\,mm^4 \text{ (OneSteel 2012)}$$

Therefore:

$$\boldsymbol{\sigma} = \frac{\mathbf{102300}\,\boldsymbol{N \cdot mm \cdot} \mathbf{20}\,\boldsymbol{mm}}{\mathbf{32.0 \cdot 10^3}\,\boldsymbol{mm^4}}$$

$$\boldsymbol{\sigma} \approx \mathbf{64}\ \boldsymbol{MPa}$$

OneSteel (2012) indicates the yield stress 40 x 6 FMS is 360 MPa. It is again clear that the proposed design is highly suitable for withstanding loading scenario 2.

Analysis of the two critical aspects of the proposed frame has confirmed the suitability of the design. The SHS span across the 'front' of the frame meets the serviceability requirement of minimising deflection to 2.6 mm when a central 100kg load is applied. The handle complies with AS 1428.1-2008 as it is capable of supporting an 1100 N load, at any position and direction.

4.2.9 Design Outcomes - Frame

This section has successfully detailed the design process for the frame design subsystem. The design is seen to have achieved all relevant design ambitions highlighted in Subsection 4.2.1. Figure 4.17 depicts the completed design for the frame with the computer and Laminex™ sheeting attached. It is important to note that the open area to the right of the computer will be covered by the three experiment bases. Appendix I contains detailed manufacturing drawings completed as part of this process. The completed frame will have a total mass around 95 kg.

Figure 4.17 - Overview of frame design results

4.3 Experimental Requirements and Limitations

Prior to commencing the presentation of the experiment design process it is seen as important to briefly summarise a number of significant design requirements and limitations. Requirements include a number of key experiment service and design requirements which will influence the remainder of this chapter. Limitations include the strict availability of area on which to mount the three experiments.

4.3.1 Available Experiment Area

Considering the design of the frame has been finalised the total area available for the three experiments is now fixed. The design of the experiments must involve careful consideration of these dimensions. Figure 4.18 demonstrates the available experimental area. The perimeter highlighted in blue clearly defines where the experiments are to be mounted.

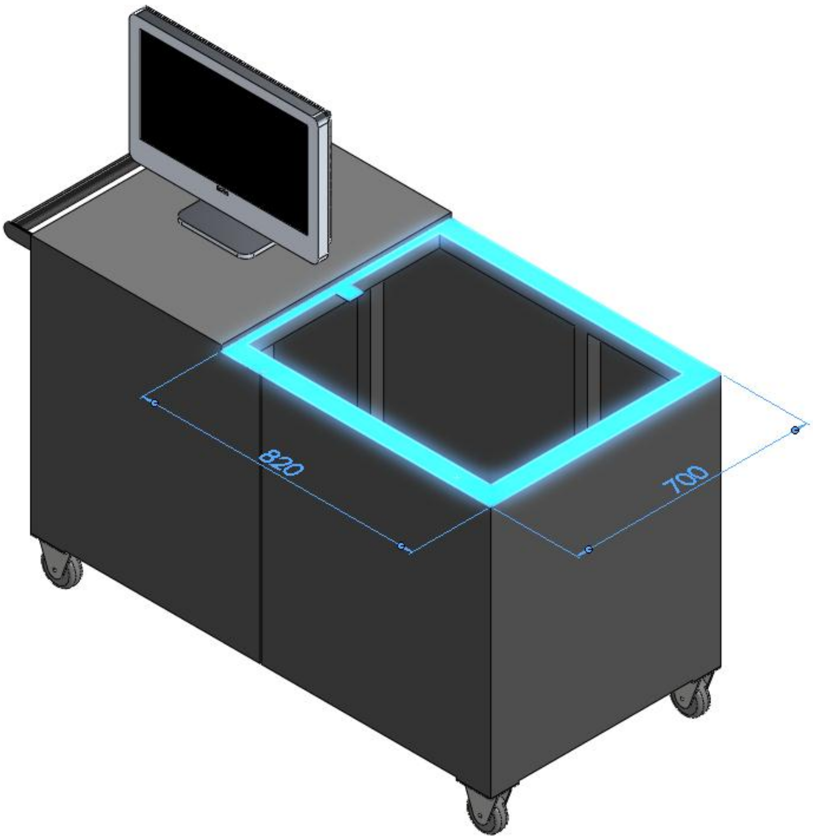


Figure 4.18 - Overview of area available for mounting of the three experiments

The area available involves a total length of 820mm and a total width of 700mm. The experiments will be orientated parallel to the front of the frame in order to maximise the length of material that can be mounted and manipulated on each experiment. This orientation will assist in ensuring the experiments have appreciable visual results in accordance with Primary Design Objective number 5 (refer to Subsection 3.2.1).

Figure 4.19 demonstrates this orientation and details the available area for each experiment. Given a protective cover needs to be later designed and installed over the top of all three experiments a 10mm offset line in shown inside the of the outer perimeter of the area. This line therefore defines the actual free area available for experiment design. As a result each experiment has an area of 226mm x 800mm available. A material thickness of 8mm (steel) has been initially assumed for the experiment base, this must be later analysed to ensure the appropriateness of the selection.

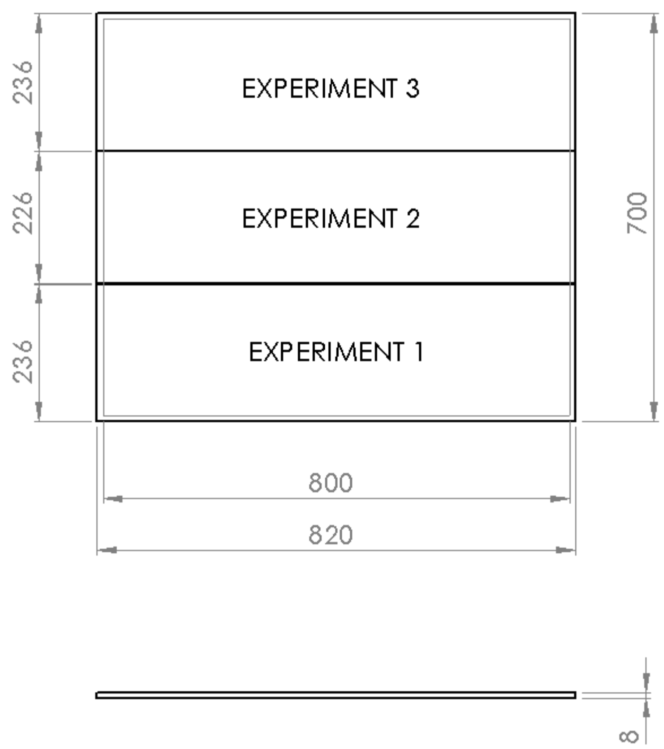


Figure 4.19 - Overview of experiment orientation and available experimental area

4.3.2 Experiment Base Design Modification

In accordance with the conclusions of Section 3.5, the experiment base shall be separated in three separate units as opposed to a single unit as initialling proposed. Subsection 3.5.2 (Ecological Considerations) found that this project should design for ease of replacement or updating of components. Physically separating each experiment base will allow for the individual removal, repair, replacement or modification of any of the experiments without the need to replace the entire experimental base. This concept modification will simplify maintenance and offer ecological benefits to the project. It is proposed that a small gap of around 1mm will separate each experiment base.

4.3.3 Experiment Service Requirements

Remaining design work in this chapter will have a strong focus on optimum experiment material selection and maximum loading conditions. As part of this process it is important to have a formally identified 'life span' for the completed project. This will form the basis for fatigue calculations which must be performed as part of the design of each experiment. Performing fatigue life calculations will theoretically ensure materials are not stressed beyond a level which may ultimately result in poor repeatability of results or complete material failure.

The design life for this apparatus is for twenty five years of continues service. During this period it has been assumed that each experiment will experience ten complete stress cycles per day.

Therefore,

$$25\, years \cdot 365\, days/yr \cdot 10\ cycles/day \quad = \quad \mathbf{91,250\ cycles}$$

Based on this result, a figure of **100,000 cycles** shall be adopted for all fatigue calculations. It is noted that this is considered to be a highly conservative prediction of the number of cycles the apparatus may experience.

4.3.4 Generic Requirement of Experiment Design

Chapters 1 through 3 of this document identified a number of requirements which should be carefully considered during the preliminary design of each of the three proposed experiments. Compliance with these requirements will ensure achievement of project objectives to optimise educational benefits to future users. Primarily, the experiments should:

- Accurately demonstrate the relevant theory (refer to 1.4.4)
- Comply with the limited physical dimensions available for mounting of on the frame (refer to 4.3.1)
- Be designed for a 100,000 cycle life (refer to 4.3.3)
- Use a material commonly used in industry (refer to 3.2.1)
- Be designed to ensure maximum visual results (refer to 3.2.1)
- Be designed in a manner that appears familiar to students (refer to 3.2.1)
- Be designed to ensure ease of replacement or updating of components (refer to 3.5.2)

Specific design requirements relating to individual experiment have been briefly identified during the introduction of each design subsystem.

4.4 Shaft Torsion Experiment Design

As outlined in Section 1.4, the Shaft Torsion Experiment will physically demonstrate the angular deformation and shear stress associated with applying a torque to a shaft of circular cross-section (600mm long). This applied torque must be limited so as to only induce stresses within the elastic range of the material. Figure 4.20 shows a concept of the proposed design.

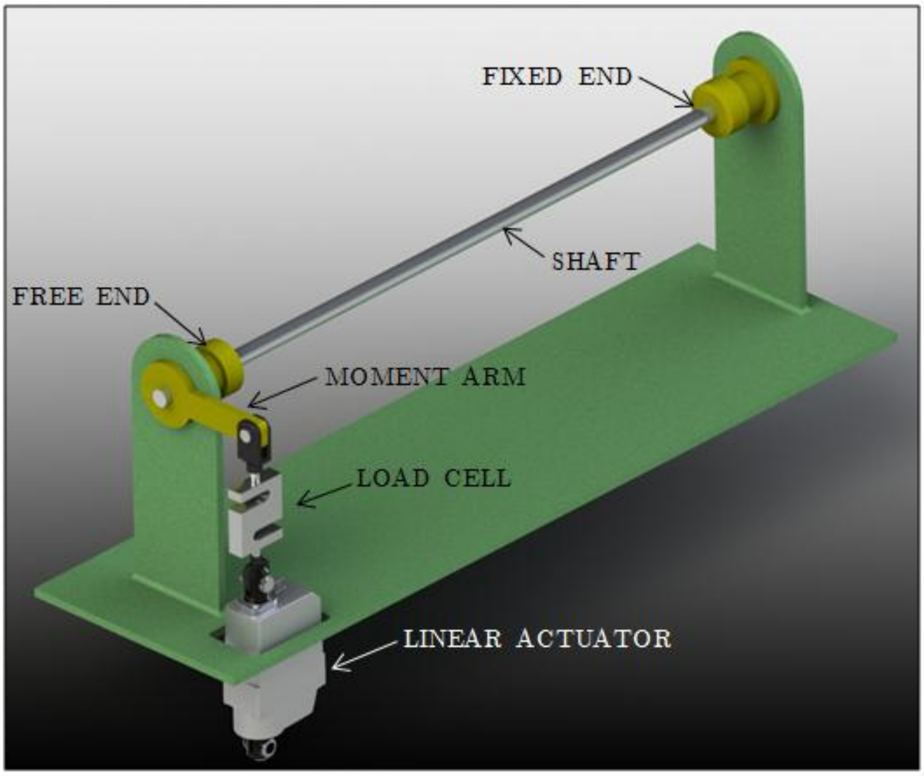


Figure 4.20 - Proposed concept design of Shaft Torsion Experiment

As indicated, one end of the shaft is completely restrained while the other is restrained in all direction however free to rotate in a plane perpendicular to the orientation of the shaft. A short moment arm (100mm) is attached to the free end of the shaft which is used to generate the desired torque. Loads are applied to this moment arm by varying the stroke of a linear actuator. The load cell is designed to independently provide feedback of the actual applied loads. Measurement of deflections will be achieved via a rotary encoder (not shown) attached to the free end of the shaft. A strain gauge (not shown) attached near the fixed end of the shaft will provide independent feedback of strain and therefore the stress induced in the material. A webcam (not shown) will also provide feedback to remote users.

4.4.1 Relevant Theory – Shaft Torsion

The section provides a brief summary of theory relating specifically to the shaft torsion experiment. Beer and Johnston (2009) point out that if a torque is applied to the free end of a circular shaft (fixed at the other end), the shaft will twist. The angle through which the free end of the shaft rotates is known as the angle $\boldsymbol{\phi}$, called the angle of twist. This phenomenon is demonstrated in Figure 4.21.

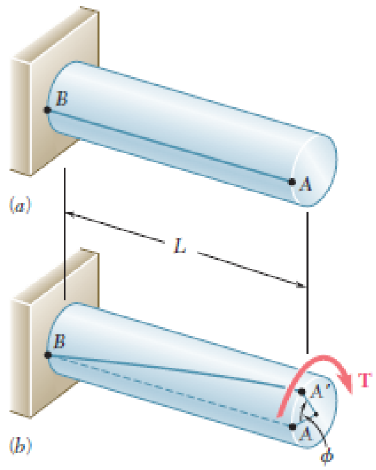


Figure 4.21 - Example of deformation associated with an applied torsion (Beer & Johnston 2009)

Beer and Johnston (2009) suggest that observations have shown that within the elastic limit of a material the angle of twist ($\boldsymbol{\phi}$) is directly proportional to the magnitude of an applied torque ($\boldsymbol{T}$). In addition, $\boldsymbol{\phi}$ is directly proportional to the length $\boldsymbol{L}$ of the shaft, therefore if the length of an identical shaft is doubled, the angle $\boldsymbol{\phi}$ could be expected to be exactly twice the previous value (Beer & Johnston 2009). $\boldsymbol{\phi}$ is theoretically calculated using Equation 4.1.

$$\boldsymbol{\phi} = \frac{\boldsymbol{TL}}{\boldsymbol{JG}} \tag{4.1}$$

Where:

$\boldsymbol{G}$	Modulus of Rigidity
$\boldsymbol{L}$	Length
$\boldsymbol{J}$	Polar moment of inertia
$\boldsymbol{T}$	Torque

The modulus of rigidity ($\boldsymbol{G}$) for a material is the shear equivalent of the modulus of elasticity ($\boldsymbol{E}$) used for axially applied loads. $\boldsymbol{G}$ is calculated using Equation 4.2, where $\boldsymbol{\tau}$ represents shearing stress and $\boldsymbol{\gamma}$ shearing strain.

$$\boldsymbol{G} = \frac{\boldsymbol{\tau}}{\boldsymbol{\gamma}} \tag{4.2}$$

The polar moment of inertia ($\boldsymbol{J}$) is again the shear equivalent of the commonly used moment of inertia ($\boldsymbol{I}$). $\boldsymbol{J}$ for a solid circular shaft is calculated using Equation 4.3, where $\boldsymbol{c}$ is the radius of the shaft.

$$\boldsymbol{J_{solid}} = \frac{1}{2}\boldsymbol{\pi c^4} \tag{4.3}$$

Considering shear stress in a circular shaft in torsion varies linearly from zero at the shaft centre to a maximum at the shaft's outer radius. Maximum shear stress ($\boldsymbol{\tau_{max}}$) is given by Equation 4.4.

$$\boldsymbol{\tau_{max}} = \frac{\boldsymbol{Tc}}{\boldsymbol{J}} \tag{4.4}$$

In accordance with the Maximum Shear Stress Theory as presented in Beer and Johnston (2009), where $\boldsymbol{\tau_{max}}$ is the maximum shear stress and $\boldsymbol{S_{sy}}$ is the shear yield strength of the material:

$$\boldsymbol{\tau_{max}} \geq \boldsymbol{S_{sy}} = \boldsymbol{failure}$$

$$\boldsymbol{\tau_{max}} < \boldsymbol{S_{sy}} = \boldsymbol{safe}$$

Following presentation of this relevant theory it is clear that calculations must be performed to ensure that the shaft is not subjected to a shear stress $\boldsymbol{\tau_{max}}$ in excess of material shear yield stress, $\boldsymbol{S_{sy}}$. In addition, calculations must be performed to ensure the achievement of a number of previously defined design objectives.

4.4.2 Material Selection

Aluminium was selected for use on this experiment in accordance with the requirements outlined in Primary Design Objectives number five and nine. These design ambitions are summarised below.

5) Design experiments to ensure appreciable visual results
9) Experiments should involve materials commonly used in industry

Inspection of Equation 4.1 (angle of twist) reveals that materials which have a lower value of modulus of rigidity $\boldsymbol{G}$, will exhibit larger angular deflections when subjected to the same load. Beer and Johnston (2009) indicate that structural steel for instance, has a modulus of rigidity of 77.2 GPa, while the majority of aluminium alloys have values in the order of 27 GPa. Despite this large difference in $\boldsymbol{G}$ values, the shear yield strength of these materials remains similar. It can therefore be concluded that use of aluminium will provide significantly larger deflections than steel for a given load and material cross-section.

A check of the local availability of smaller diameter aluminium round bar revealed the following details contained in Table 4.1

Table 4.1 - Local availability of high strength aluminium round bar

Diameter (mm)	**Alloy**	**Modulus of Rigidity** (GPa)	**Approximate Shear Yield Strength** (MPa)
10	6060 T5	26 (OneSteel 2012)	77 (OneSteel 2012)
12	6060 T5	26 (OneSteel 2012)	77 (OneSteel 2012)
16	6061 T6	26 (Beer & Johnston 2009)	140 (Beer & Johnston 2009)

In order to determine the maximum shear stress that each of these materials can be subjected to, a number of fatigue strength calculations have been performed. This fatigue strength is to be based on the predicted number of cycles the material will experience. Subsection 4.3.3 identified that each experiment should be designed for 100,000 cycles. The standard method with which to determine the fatigue life of a material is through the use of an S-N curve.

Several values must be calculated before an S-N curve can be plotted. These include the endurance limit of the material ($\boldsymbol{S_n}$) and the 10^3 cycle strength ($\boldsymbol{S_f}$). It is important to note that it has been assumed that the shaft on experiment one will be subjected to completely reversed loadings, despite this not being the operational intention of the experiment. This is seen as conservative approach which will ensure the longevity of the apparatus regardless of future loading conditions.

Juvinall and Marshek (2005) propose that $\boldsymbol{S_f}$ for torsional loads can be calculated using Equation 4.5. In this equation $\boldsymbol{S_{us}}$ is the ultimate shear strength of the material and $\boldsymbol{C_T}$ represents the temperature correct factor.

$$\boldsymbol{S_f = 0.9\, S_{us}\, C_T} \tag{4.5}$$

Considering the experiments are to be performed at room temperature, $\boldsymbol{C_T}$ will be equal to one, and therefore not influence the results. Table 4.2 summarise the mechanical properties and calculated $\boldsymbol{S_f}$ of each of the two available alloys.

Table 4.2 - Summary of mechanical properties of available aluminium round bar

Alloy	Ultimate Tensile Strength, S_u (MPa)	Ultimate Shear Strength, S_{us} (MPa)	S_f (MPa)
6060 T5	150 (OneSteel 2012)	95 (OneSteel 2012)	85.5
6061 T6	260 (Beer & Johnston 2009)	165 (Beer & Johnston 2009)	148.5

The endurance limit S_n for aluminium is commonly based on the 5×10^8 cycle strength. Equation 4.6 is taken from Juvinall and Marshek (2005) and outlines the method for calculating the endurance limit for torsional loads.

$$S_n = S'_n C_L C_G C_S C_T C_R \tag{4.6}$$

Where,

S'_n	R.R. Moore, endurance limit
C_L	Load factor
C_G	Gradient factor
C_S	Surface factor
C_T	Temperature factor
C_R	Reliability factor

Experimental results presented by Juvinall and Marshek (2005) demonstrate that for most common alumium alloys:

$$S'_n = 0.4\, S_u$$

Considering this relationship, S_n for each of the two alloys can now be calculated. The results are presented in the Table 4.3.

Table 4.3 – Summary of endurance limit calculations for available aluminium alloys

	6060 T5	6061 T6
S'_n	60 $0.4\, S_u$	104 $0.4\, S_u$
C_L	0.58 Torsion	0.58 Torsion
C_G	0.9 10mm < diameter < 50mm	0.9 10mm < diameter < 50mm
C_S	0.8 Machined or cold drawn	0.8 Machined or cold drawn
C_T	1.0 Ambient temperature	1.0 Ambient temperature
C_R	1.0 50% reliability	1.0 50% reliability
S_n	**25 MPa**	**43.5 MPa**

Both the 10^3 cycle strength $\boldsymbol{S_f}$ and the endurance limit of the materials $\boldsymbol{S_n}$ have been determined The S-N curve can now be plotted and the 1×10^5 cycle strength graphically determined (refer to Appendix I).

Results of this analysis have shown 1×10^5 cycle strengths of approximately 55 MPa for the 6060 T5 alloy and 100 MPa for the 6061 T6 alloy. Comparison of these findings with the shear yield strengths shown in Table 4.1, indicates that both alloys can be loaded to approximately 70% of their respective yield capacities without concern of fatigue failure.

Appendix J contains the details of MATLAB script written to theoretical simulate the results of conducting the shaft torsion experiment. This script receives a number of inputs. Using the theories presented in Subsection 4.4.1, the script returns the maximum load that can be applied to the end of the moment arm. In addition the resulting angle of twist is also calculated. Inputs to the script include the shaft diameter, modulus of rigidity, shear yield strength and length in addition to the length of the moment arm. The maximum percent of the yield strength that the shaft should be stressed to must also be input into this script. Results of running the simulation with the three available materials are shown in Tabe 4.4.

Table 4.4 - Results of MATLAB simulation - Shaft Torsion

Diameter (mm)	**Alloy**	**Shaft Length** (mm)	**Moment Arm length** (mm)	**Maximum Load** (N)	**Angle of twist** (deg)
10	6060 T5	600	100	106	15.4
12	6060 T5	600	100	182	12.9
16	6061 T6	600	100	788	17.5

From these results the **16mm diameter 6061 T6** shaft was selected as it exhibits the largest maximum deflection of the three sections. Although the load required to achieve this deflection is the highest of the three, this is not seen as an important factor for selection. Use of larger, more realistic loads will assist in the achievement of Objective 13 (sensory awareness) from the 2002 ABET Colloquy as identified in Chapter 2.

4.4.3 Primary Component Selection

The final stage of the design process for Experiment One is to specify the primary hardware required for automation of the apparatus. Primary considerations during this process will be the relevant capacities, availability and the overall physical dimensions. The components to be selected include:

- 1 x Linear actuator
- 1 x Load cell
- 1 x Strain gauge rosette
- 1 x Rotary encoder

Linear Actuator – Subsection 4.4.2 concluded that a 16mm diameter solid aluminium round bar shall be manipulated by Experiment One. Results of the MATLAB simulation have shown that the actuator must be capable of subjecting the end of the moment arm to a maximum force no less than 788 N. In addition it is clearly desirable for the actuator to have minimum physical dimensions. The stroke of the actuator must also be sufficient to move the moment arm through the maximum angle of twist (17.5 degrees). Figure 4.22 demonstrates this principal. Clearly the stroke length need not be particularly large.

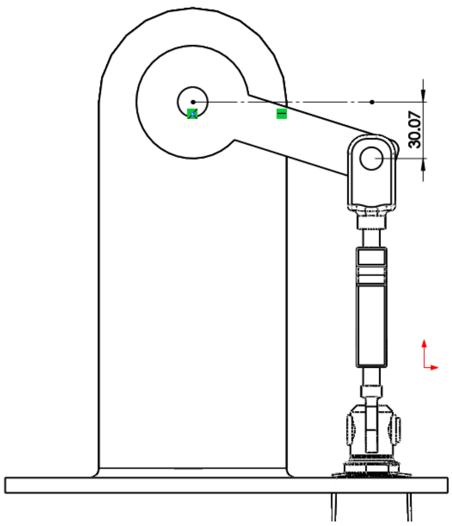


Figure 4.22 - Vertical displacement of moment arm

In accordance with the advice of Bowtell (2013) linear actuators for this project are to be supplied by Linak Australia. The model selected is the LA23 actuator (see Figure 4.23) which features a compact design and maximum thrusts up to 2500N. Appendix I contains a summary of technical specifications of this actuator.

Figure 4.23 - Linak 23 Techline Actuator (Source: www.linak.com.au)

Load Cell – The load cell must be capability of withstanding the forces delivered to it by the linear actuator (nominally up to 1000N). In addition this component must also have minimal outer dimensions so that it is clearly visible above the upper surface of the experiment base. The load cell selected is the PT4000 universal S-BEAM by PT Global (see Figure 4.24). Selected technical specifications of this component have been included in appendix H.

Figure 4.24 - PT Global PT4000 load cell (source: www.ptglobal.com)

Strain gauge rosette – In order to independently determine the amount of shearing strain and therefore stress present in the shaft it is proposed that a strain gauge rosette be attached near the fixed end of the shaft. A delta strain gauge rosette is suggested for this purpose. The measurements from the three individual strain gauges can then be used to determine maximum shear stress in the shaft. Figure 4.25 depicts a scenario similar to that of the proposed shaft torsion experiment.

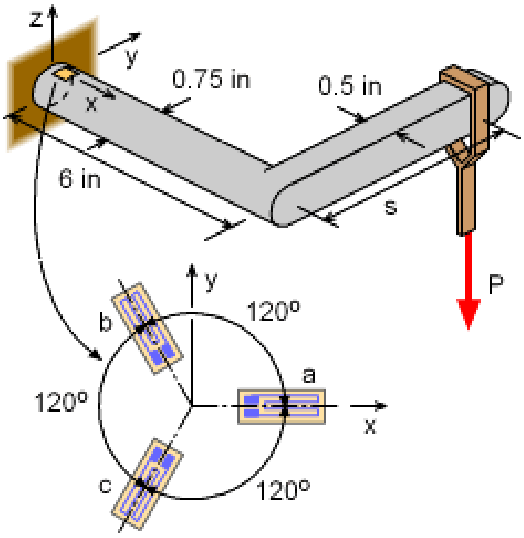


Figure 4.25 - Example of delta strain gauge rosette (source: www.ecourses.ou.edu)

Rotary Encoder – The rotary encoder required by this experiment must be capable of being fixed to the free end of the aluminium shaft and accurately measure the exact angle of twist. The selection of a specific rotary encoder has been deemed to be outside the author's expertise and as such must be completed by a technical expert prior to apparatus manufacturing. This approach is in accordance with the findings of Subsection 3.5.3 (Ethical Issues)

4.4.4 Design Outcomes - Shaft Torsion Experiment

This section has successfully detailed the preliminary design process for the Shaft Torsion Experiment subsystem. The design is seen to have achieved all relevant design objectives highlighted in Subsection 4.3.4. Preliminary technical drawings of the experiment base for this experiment are contained in Appendix I. Evidently the design work completed at this point is not to a manufacture-ready stage. Completion of the designs to this standard will form part of the suggested future work of this research project. Figure 4.26 below demonstrates the design outcomes of this design sub-section with key outcomes notes.

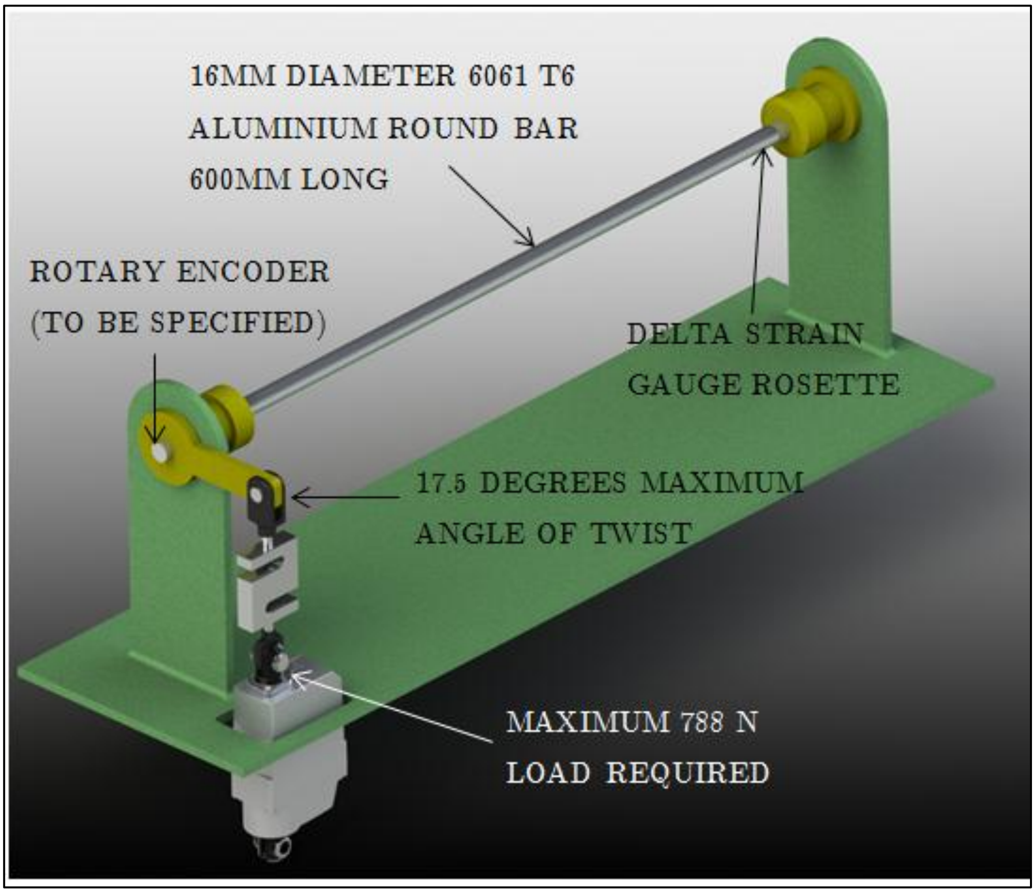


Figure 4.26 - Preliminary design outcome - Shaft Torsion Experiment

4.5 Unsymmetric Bending Experiment Design

As outlined in section 1.4, the Unsymmetric Bending Experiment will demonstrate the concept of unsymmetric bending in a cantilever beam section (unequal angle). This experiment will involve the student theoretically calculating the principal centroidal axes (PCA's) and the neutral axis (N.A.) for a fixed cross-section and user defined orientation. Once this is complete the student will operate this experiment by inputting this orientation in order to physically validate the calculated N.A. Confirmation of N.A. orientation will be achieved via inspection of the relative end displacements (along y & z axes) of the cantilevered section supporting a free hanging mass. This theory is presented and discussed in Subsection 4.5.1. Figure 4.27 shows a concept of the proposed design.

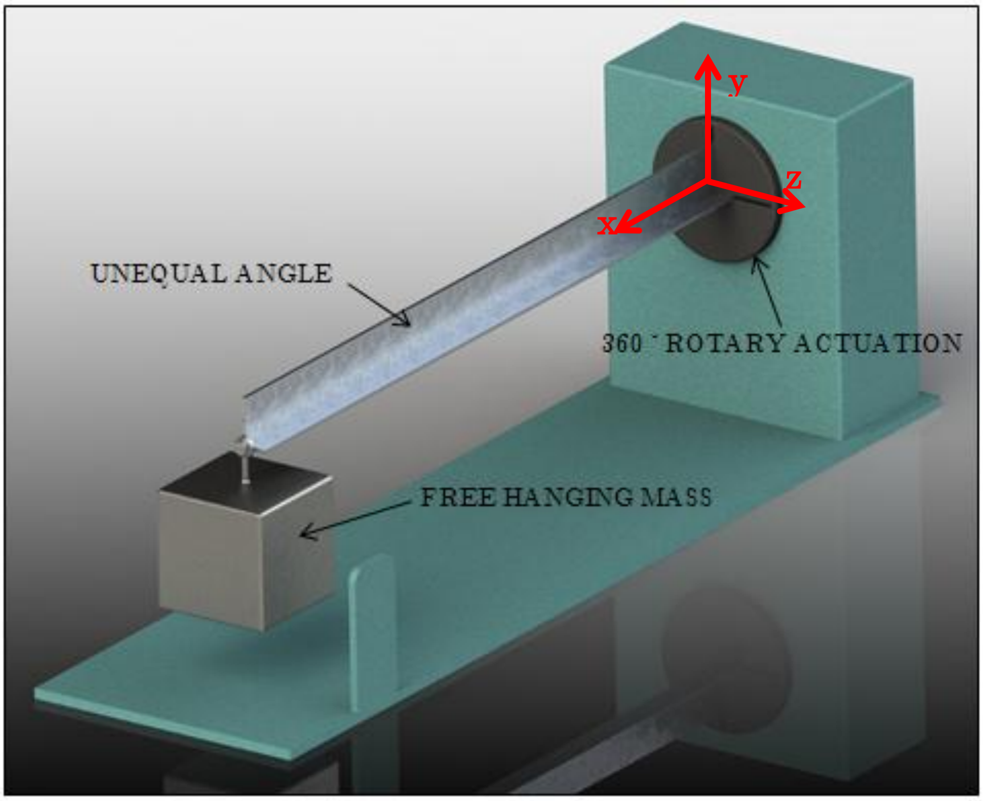


Figure 4.27 - Proposed concept design of Unsymmetric Bending Experiment

As indicated the supported end of the unequal angle section is capable of indexing through 360 degrees. The free hanging mass will ensure the application of a constant bending moment permanently aligned about the z axis. In this way the effect of altering the orientation of the section can be made physically apparent to user. This is intended to strongly reinforce the student learning experience.

Measurements of the relative deflections shall be digitally relayed to the users via two ultrasonic proximity sensors (not shown). These are to be aligned to measure the relative displacement of the free hanging mass in the y and z direction. A webcam will also provide visual feedback, to ensure remote users trust the authenticity of results. This is in accordance with Primary Design Objective number eight (refer to Subsection 3.2.1). Providing visual feedback to remote users is also considered necessary to ensure the apparatus fulfils objective 13 of the 2002 ABET Colloquy to develop the students sensory awareness of real-world problems. No strain gauges are to be initially applied to this experiment.

4.5.1 Relevant Theory – Unsymmetric Bending

This section provides a brief summary of the complex theory relating specifically to the proposed Unsymmetric Bending Experiment. The theories involved are among the most complex in MEC2402. It is noted by the author that no single resource currently available to USQ MEC2402 students, adequately describes the relevant concepts on a stand-alone basis. As a result some literature sources external to the course material have been referenced in this section.

Beer and Johnston (2009) assert that many common bending problems involve members that have at least one plane of symmetry and are subject to bending couples acting only in that plane. Due to this member symmetry and loading condition it would be reasonable to suspect that bending will occur in that plane. Figure 4.28 highlights this concept. Note the location of the neutral axis (N.A.) which represents the orientation of a plane passing through the centroid of the member where normal stress is zero. Deflection of a beam will therefore always be in a direction perpendicular to this plane. When a moment couple is applied about a plane of symmetry, the N.A. is found coincident with the axis of the couple.

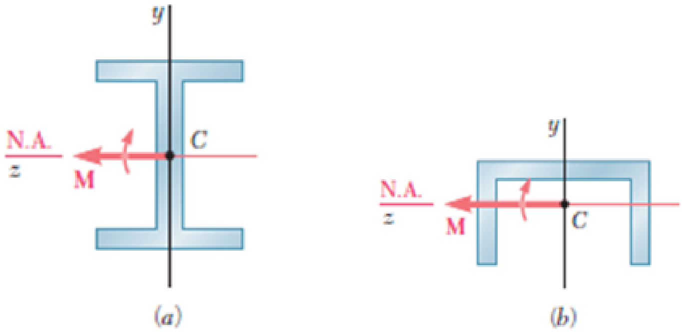


Figure 4.28 - Example of symmetric bending (Beer & Johnston 2009)

Consider however the situation where an applied bending couple is not applied coincident with an axes of symmetry. This could be either because they act in a different plane, or because the member does not possess any planes of symmetry, as is the case with unequal angle sections. Figure 4.29 demonstrates some examples of unsymmetric bending. Note in these examples how the N.A. is no longer coincident with the orientation of the moment couple.

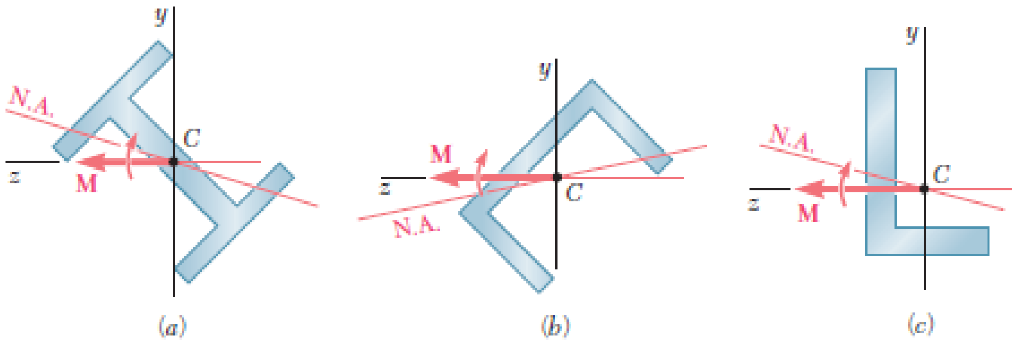


Figure 4.29 - Examples of unsymmetric bending

To understand this phenomenon it is first necessary to understand a number of underlying principles. Consider an arbitrary beam cross-section with the centroid identified. This section has an infinite number of centroidal axes which can be identified by drawing a line passing through the centroid at any orientation. Figure 4.30 illustrates this concept.

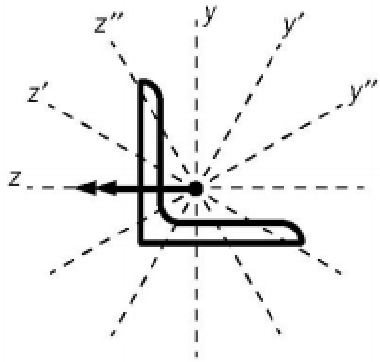


Figure 4.30 - Example of centroidal axes for an arbitrary cross-section (USQ 2010)

USQ (2010) indicates that the most important of these centroidal axes are the principal centroidal axes (PCA's). It can be concluded that if a given cross-section has an axis of symmetry, that this axis will also be a principal centroidal axis. The second PCA will always be orientated perpendicular to the first. Figure 4.31 demonstrates the orientation of the PCA's of the section from Figure 4.30. All given sections have two principal centroidal axes even if they are unsymmetric.

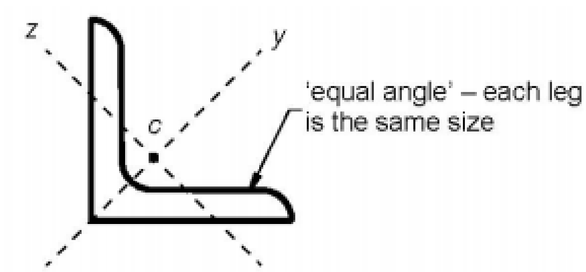


Figure 4.31 - Orientation of principal centroid axes in an equal angle profile

By inspection it is clear that the y axis PCA in Figure 4.31, is a plane of symmetry for the equal angle section. Therefore the first PCA is orientated at 45° from either flange with the second orientated perpendicular to the first. Both PCA's must pass through the centroid of the cross-section. If no axis of symmetry exists however, the precise orientation of the PCA's cannot usually be determined by inspection alone. In this situation mathematical tools are required. These are detailed in the following paragraphs.

Now that the PCA have been defined it is important to note the following. The N.A. of cross-section will coincide with the axis of a couple only if that couple is directed along the one of the principal centroidal axes of the cross-section. Reconsider the two examples shown below and recognise the location of the PCA's and the orientation of the moment couple relative to them.

Figure 4.32 – Examples of a moment couple aligned/misaligned with PCA
(Beer & Johnston 2009)

Clearly the unequal angle section on the right does not have the moment couple applied to either of its PCA's. As a result the neutral axis is misaligned to the couple at an as of yet undetermined orientation. The method for determining this orientation shall now be presented.

Mathematically the principal centroidal axes are defined as the axes for which the mixed moment of inertia I_{zy} (or product of inertia) is zero. Using the parallel axes theorem for the mixed moment of area gives the following, Equation 4.6.

$$\boldsymbol{I_{zy}} \quad = \quad \boldsymbol{I_{z'y'}} + \boldsymbol{A_{zy}} \tag{4.6}$$

Craig (2011) provides excellent examples and descriptions of the process of calculating the product of inertia for various cross-sections. Beer and Johnston (2009) and USQ (2010) both provide particularly superficial introductions into these calculations.

The relevant example of an unequal angle shall now be used for further explanation of these concepts. PCA orientation (θ) relative to a set of coordinate axes is then found analytically or through the use of a Mohr's circle (shown below).

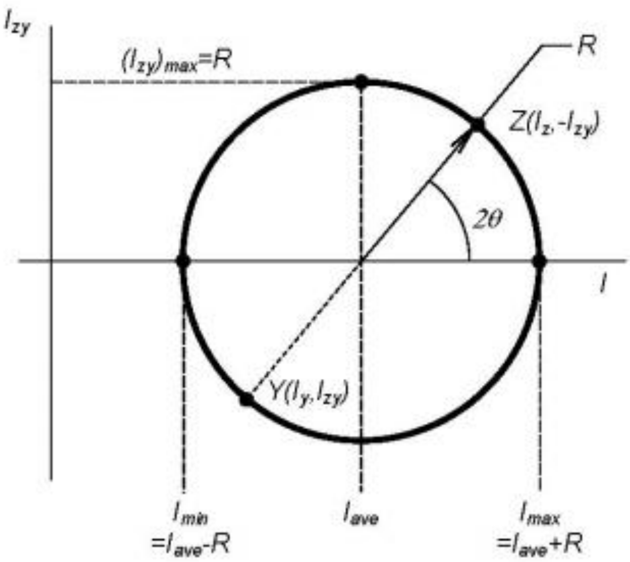


Figure 4.33 - Mohr's circle for determining the orientation of PCA (USQ 2010)

From this Mohr's circle it is clear that the two values I_z and I_y must be determined about an arbitrarily assigned axes. For simplicity the following is suggested.

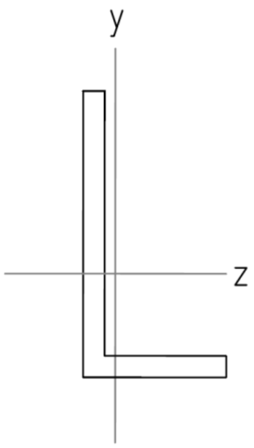


Figure 4.34 - Suggested orientation of the y and z axes for calculation of I values

Analysis of the Mohr's circle will provide both the orientation of the PCA's as well as the values of I_{min} & I_{max}. These values refer to the second moment of area of the section about each of the PCA's. Figure 4.35 details the results of this process.

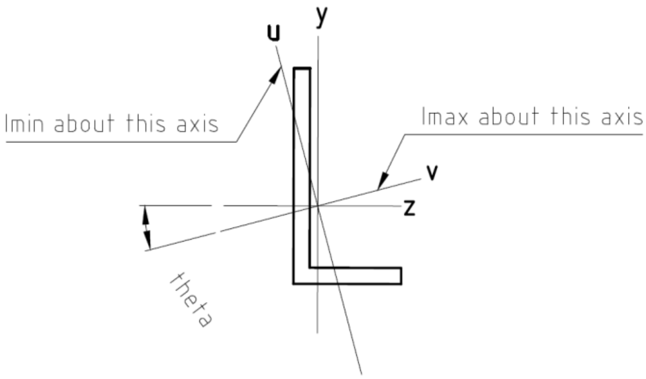


Figure 4.35 - Results obtained via the use of Mohr's circle

Once the orientation of the PCA's has been determined it is clear that aligning a bending couple with these axes will result in a N.A. coincided with the plane of the applied moment. This is concept is illustrated below.

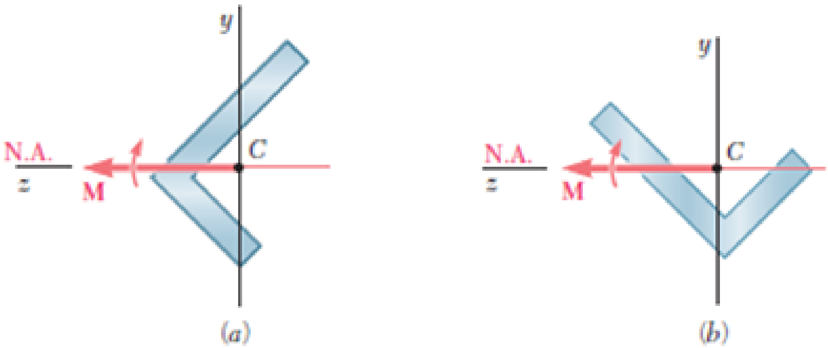


Figure 4.36 - Alignment of bending couples with PCA's of unequal angle
(Beer & Johnston 2009)

Consider the situation presented earlier (refer to Figure 4.32) in which this bending couple was misaligned to the PCA's. In this case the neutral axis is always located between the couple vector and the axis corresponding to the minimum second moment of area. The orientation of this N.A. can be mathematically determined using Equation 4.7 with reference to Figure 4.37.

$$\tan\phi = \frac{I_u}{I_v}\tan\theta \tag{4.7}$$

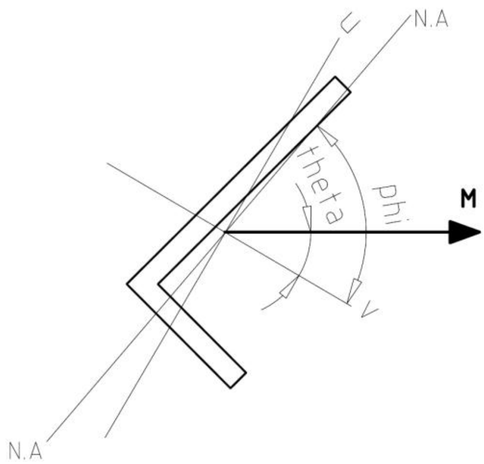


Figure 4.37 - Calculation of N.A when moment couple is misaligned to PCA's

Note that theta here is different to the theta used previously to determine the orientation of the principal centroidal axes. Several appropriate examples of these calculations are found in Beer and Johnston (2009) and USQ (2010).

The theory presented in this section has provided an appropriate background into the methods a student would have to undertake prior to attempting the proposed Unsymmetric Bending Experiment. Following presentation of this theory it clear that calculation must be performed to ensure that the unequal angle and free hanging mass selection are suitable. This analysis must ensure that neither plastic deformation nor premature fatigue failure occurs in the section whilst ensuring maximum visual results.

4.5.2 Material Selection

Aluminium has again been selected for use on this experiment for similar reasons as with the Shaft Torsion Experiment. Given the experimental result are to be based on the relative deflections of a cantilever section the following Equation 4.8 can be used to determine the deflection $\boldsymbol{\delta}$.

$$\boldsymbol{\delta} = \frac{\boldsymbol{PL^3}}{\boldsymbol{3EI}} \tag{4.8}$$

Where:

$\boldsymbol{P}$	Force
$\boldsymbol{L}$	Length
$\boldsymbol{E}$	Modulus of elasticity
$\boldsymbol{I}$	Moment of inertia

Inspection of Equation 4.8 reveals that materials which have a lower modulus of elasticity $(\boldsymbol{E})$ will exhibit larger deflections. Beer and Johnston (2009) indicate that structural steel has a modulus of elasticity of 200 GPa while most alumium alloys have values in the order of 70 GPa. It can therefore be concluded the use of a suitably strong alumium alloy will provide significantly larger deflections than steel for a given load and material cross-section.

A check of the local availably of small unequal aluminium angle sections revealed the following details contained in Table 4.5.

Table 4.5 - Selection of locally available aluminium unequal angle

Size (H x W x T) (mm)	**Alloy**	**Modulus of Elasticity** (GPa)	**Tensile Yield Strength** (MPa)	**Ultimate Tensile Strength** (MPa)
20 x 12 x 1.6	6060 T5	68.3 (OneSteel 2012)	145 (OneSteel 2012)	186 (OneSteel 2012)
25 x 12 x 3	6060 T5	68.3 (OneSteel 2012)	145 (OneSteel 2012)	186 (OneSteel 2012)
40 x 20 x 3	6060 T5	68.3 (OneSteel 2012)	145 (OneSteel 2012)	186 (OneSteel 2012)

In order to determine the maximum normal stress that the 6060 T5 alloy should be subjected to, fatigue calculations need to be performed. These calculations must involve the 100,000 cycle desired life span (refer to Subsection 4.3.3). The majority of this process will be based on the descriptions provided in Subsection 4.4.2. Results in this case will however refer to normal stress as opposed to shear stress.

Juvinall and Marshek (2005) indicate that $\boldsymbol{S_f}$ for bending loads can be calculated using Equation 4.9, where $\boldsymbol{S_u}$ is the ultimate tensile strength of the material and $\boldsymbol{C_T}$ again represents the temperature correction factor. As with Experiment One, $\boldsymbol{C_T}$ is again equal to unity is this situation.

$$\boldsymbol{S_f} \quad = \quad \boldsymbol{0.9\, S_u\, C_T} \tag{4.9}$$

Therefore $\boldsymbol{S_f}$ for the 6060 T5 aluminium alloy will be approximately 167 MPa. Equation 4.10 outlines the method for calculating the endurance limit $\boldsymbol{S_n}$ for bending loads. Table 4.6 details the results.

$$\boldsymbol{S_n} \quad = \quad \boldsymbol{S'_n C_L C_G C_S C_T C_R} \tag{4.10}$$

Table 4.6 - Summary of endurance limit calculation for aluminium unequal angles

	6060 T5
S'_n	74.4 $0.4\, S_u$
C_L	1.0 Bending
C_G	1.0 size < 10mm
C_S	0.8 Machined or cold drawn
C_T	1.0 Ambient temperature
C_R	1.0 50% reliability
S_n	**59.52 MPa**

Both the 10^3 cycle strength $\boldsymbol{S_f}$ and the endurance limit of the materials $\boldsymbol{S_n}$ have now been determined. The S-N curve can therefore be plotted and the 1×10^5 cycle strength graphically determined (refer to Appendix I). Results of this analysis have shown a 1×10^5 cycle endurance limit of approximately 118 MPa. This represents roughly 81% of the tensile yield strength shown in Table 4.5.

Appendix J contains details of a MATLAB script written to theoretically simulate the results of conducting the Unsymmetric Bending Experiment. This script receives a number of inputs. The theories presented in Subsection 4.5.1 are then used to return the maximum end load the beam can support when orientated to the I_{min} axis. In addition the script outputs the vertical and horizontal deflection of the beam and the orientation of the neutral axis. Inputs to the script include the orientation of the unequal angle, beam length, size and mechanical properties. The maximum percent of the yield strength that the shaft should be stressed to must also be input into this script. Results of running this simulation with the three selected cross-sections are shown in Table 4.7. Note that the section orientation shown in Figure 4.34 represents an orientation zero degrees. Positive orientation input values correspond to a counter clockwise rotation of the cross-section.

Table 4.7 - Results of MATLAB simulation - Unsymmetric Bending

Size (H x W x T) (mm)	**Alloy**	**Shaft Length** (mm)	**Maximum Load** (kg)	**Orientation** (deg)	**Max. Vertical Deflection** (mm)
20 x 12 x 1.6	6060 T5	600	0.972	250.05 (min axis)	- 30.32
25 x 12 x 3	6060 T5	600	1.803	257.00 (min axis)	- 28.65
40 x 20 x 3	6060 T5	600	5.208	255.24 (min axis)	- 17.05

From these results the **40x20x3mm 6060 T5 unequal angle** was selected based on the magnitude of the maximum load it can support. Whilst the smaller sections clearly exhibit larger deflections the use of a larger mass is considered likely to provide users with more authentic results. The 40x20x3 section is significantly larger than the other two profiles. As such, user will likely gain a better visual appreciation of the relative proportions of the unequal angle and the influence this has on orientation of the neutral axis.

4.5.3 Primary Component Selection

The final stage of the preliminary design process for Experiment Two is to specify the suggested hardware required for automation of the apparatus. Primary considerations during this process will be the relevant capacities, availability and the overall physical dimensions. The components to be selected include:

- 1 x Free hanging mass
- 1 x Rotary actuator
- 1 x Ultrasonic sensors

Free Hanging Mass – Subsection 4.5.2 concluded that a maximum mass of 5.208 kg could be suspended from the end of the cantilevered unequal angle beam. This mass should be suspended from the shear centre of the beam and be free to rotate. This rotation will ensure that the mass remains hanging in the same plane regardless of the orientation of the unequal angle. Given the deflection of the end of the beam is to be measured via the displacement of the mass it is important that the geometry of the mass is suitable. Ultrasonic sensors require relatively flat surfaces with which to measure their relative position. As a result a cube has been selected, the dimensions of which must be based on the exact mass required. This analysis shall consider both steel and aluminium as potential solutions.

Juvinall and Marshek (2005) suggest the density of steel to be approximately 7700kg/m^3 with aluminium around 2800kg/m^3. Therefore the volume of each material required to provide a 5.21 kg mass is as follows:

$$5.21\,kg/7700\,kg/m^3 \quad = \quad \mathbf{0.677 \times 10^{-3}\,m^3}\ (steel)$$

or

$$5.21\,kg/2800\,kg/m^3 \quad = \quad \mathbf{1.861 \times 10^{-3}\,m^3}\ (aluminium)$$

Taking the cube root of both these numbers reveals the length of the three-dimensions required. Each side of a cube made from aluminium will need to be 123mm while the steel just 88mm. Based on this result the steel is considered the most appropriate material. Figure 4.38 illustrates the concept.

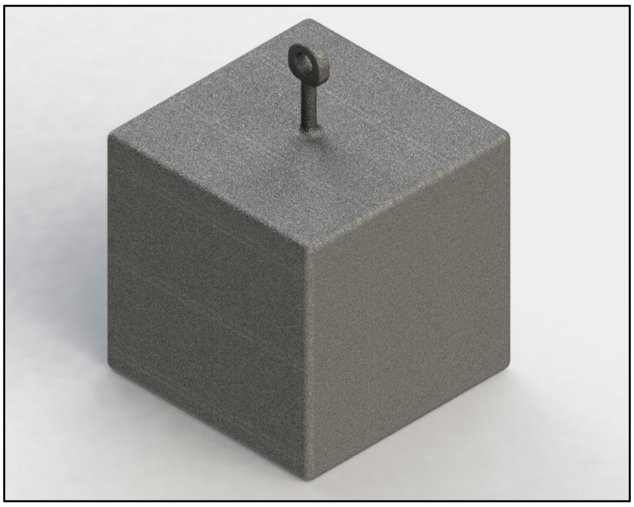


Figure 4.38 - Proposed steel free hanging mass - All sides 88mm in length

Rotary Actuator – The rotary actuator required by this experiment must be capable of supporting and indexing the unequal angle beam through 360°. The design and selection of this component has been deemed to be outside the author's expertise and as such must be completed by a technical expert prior to apparatus manufacturing.

Ultrasonic sensors – The two ultrasonic sensors required must be capable of high resolution measurement of the free hanging mass displacement in the y and z direction (refer to Figure 4.27). Critical to the successful selection of this component will be ensuring the measurement can be taken from the necessary close proximity and the surface of the proposed free hanging mass. The final selection of this component has also been deemed to be outside the author's expertise and as such must be completed by a technical expert prior to apparatus manufacturing.

4.5.4 Design Outcomes – Unsymmetric Bending

This section has successfully detailed the preliminary design process for the Unsymmetric Bending Experiment subsystem. The design is seen to have achieved all relevant design ambitions highlighted in Subsection 4.3.4. Preliminary technical drawings of the experiment base are contained in Appendix I. Evidently the design work completed at this point is not to a manufacture-ready stage. Completion of the designs to this standard will form part of the suggested future work of this research project. Figure 4.39 demonstrates the design outcomes of this design subsystem with key outcomes noted.

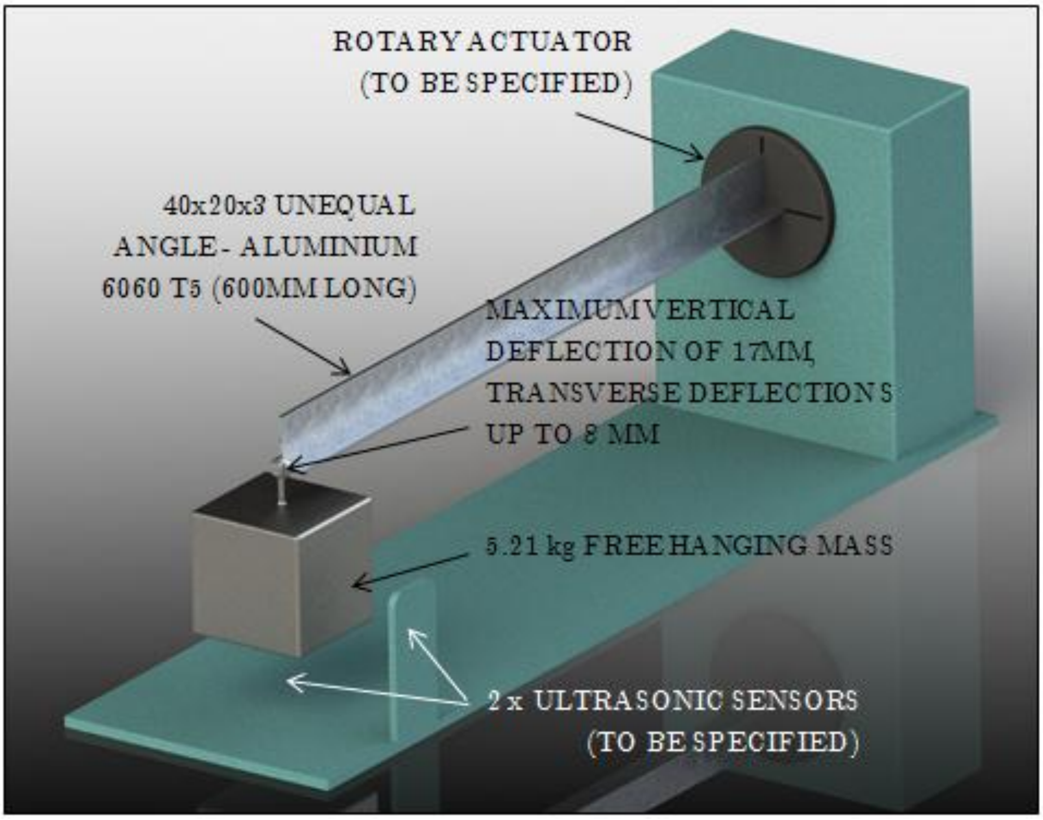


Figure 4.39 - Preliminary design outcomes - Unsymmetric Bending Experiment

4.6 Normal Stress in Beams Experiment Design

As outlined in Section 1.4, the Normal Stress in Beams Experiment will demonstrate the phenomena associated with the application of an internal bending moment to a statically determinate, constant cross-section beam. This experiment will involve the student theoretically calculating the normal strain and therefore stress on the outer surfaces of a section being subjected to a given loading condition. Confirmation of these calculations will be provided to the user via digital measurements taken from strain gauges located on the upper and lower surfaces of the experimental beam. The student will be capable of controlling the magnitude of the applied load up to a pre-defined value detailed in Subsection 4.6.2. Figure 4.40 shows a concept of the proposed design.

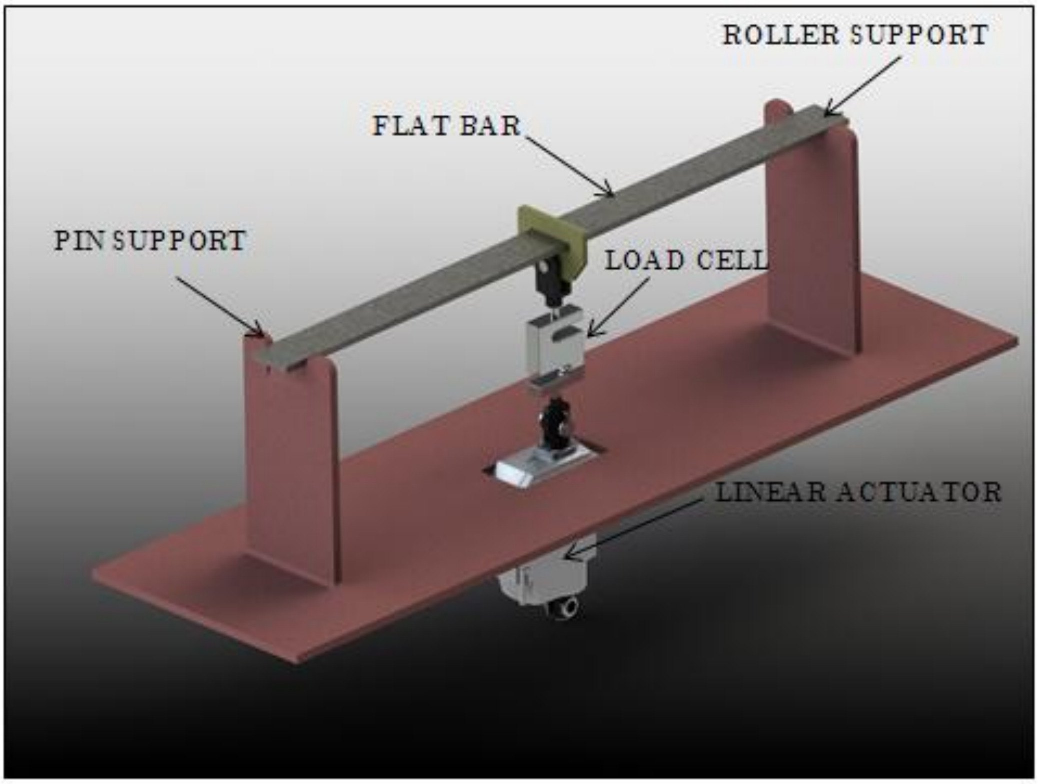


Figure 4.40 - Proposed concept design of the Normal Stress in Beams Experiment

This image demonstrates a method of load application which is similar to that of the Shaft Torsion Experiment. Relative displacement of the beam is directly influenced by the rod position of a linear actuator. The applied load is then independently measured by a load cell and relayed to the user.

In addition to the experiment measuring rates of strain, it is also proposed that the maximum deflection of the beam be provided to future users. Although calculation of beam deflection is beyond the scope of MEC2402, it is considered to be a valuable additional experimental capability. This function would likely make the Normal Stress in Beams Experiment attractive to a wide range of USQ engineering courses.

4.6.1 Relevant Theory – Normal Stress in Beams

This section provides a brief summary of the theory relating specifically to the Normal Stress in Beams Experiment. Equation 4.11 demonstrates the typically method for calculation of normal stress in beams. The formulation of each of the required values is explored in more detail throughout this section.

$$\boldsymbol{\sigma} = \frac{\boldsymbol{My}}{\boldsymbol{I}} \tag{4.11}$$

Where:

$\boldsymbol{\sigma}$	Normal stress
$\boldsymbol{M}$	Bending Moment
$\boldsymbol{y}$	Distance from neutral surface
$\boldsymbol{I}$	Moment of inertia

Beer and Johnston (2009) indicate that beams are classified according to the manner in which they are supported. Beam types such as cantilevered, fixed and simply supported are commonly used in industry. For a beam to be considered *statically determinate* the supports required by the beam must have no more than three unknown values. Figure 4.41 depicts the most common type of beam classification for introduction of this concept, the simply supported beam. The span of the beam is represented by $\boldsymbol{L}$ while $\boldsymbol{P}$ represents a given load.

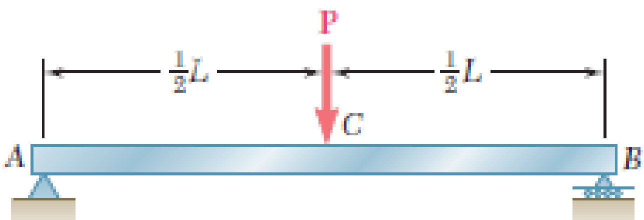


Figure 4.41 - Beam subject to a mid-span concentrated point load
(Beer & Johnston 2009)

In this case it can be seen that the beam requires two vertical support reactions and a single horizontal support reaction on the left hand side (redundant for this idealised load scenario) to achieve static equilibrium. The magnitude of the normal stress in this beam can be theoretical calculated by first solving the support reactions.

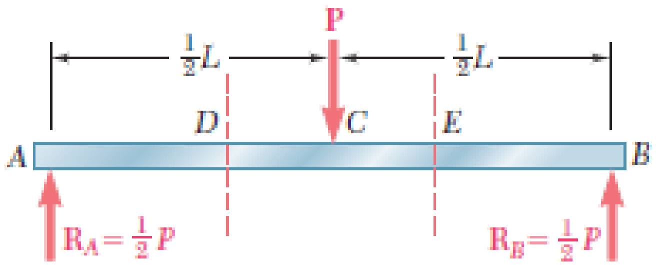


Figure 4.42 - Calculation of support reactions for a simply supported beam (Beer & Johnston 2009)

Once this has been completed the shear force and bending moment diagram can be generated. Information regarding the sense (positive or negative) of these values is found in Beer and Johnston (2009). Figure 4.43 demonstrates the results of this process.

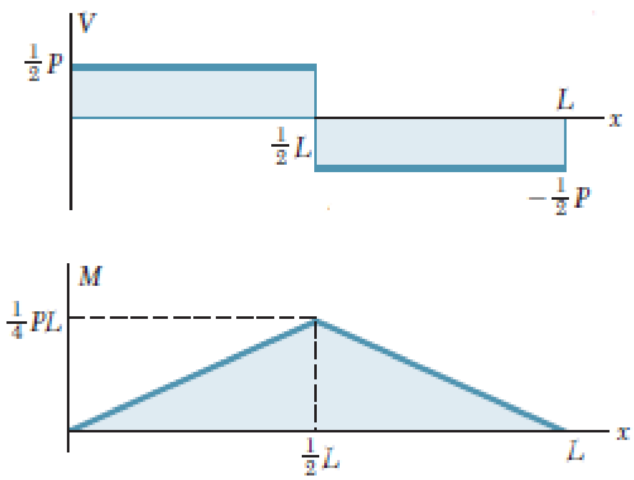


Figure 4.43 - Shear force and bending moment diagrams (Beer & Johnston 2009)

The magnitude of the bending moment $\boldsymbol{M}$ at any point along the beam can now be determined from the relevant plot. This value can then be input to Equation 4.11 with the calculated values of $\boldsymbol{y}$ and $\boldsymbol{I}$ for determination of the normal stress.

Maximum normal stress is typically the value of interest when undertaking bending calculations. This experiment is however designed to provide users with physically measured values of strain rather than stress. Equation 4.12 provides the relationship between these quantities, commonly referred to as the generalised Hooke's Law.

$$\epsilon_x = \frac{\sigma_x}{E} \tag{4.12}$$

Where,

ϵ_x	Normal strain
σ_x	Normal stress
E	Modulus of elasticity

Inspection of this equation reveals that, providing the modulus of elasticity of a material is known, the normal stress can be determined. Clearly the magnitude of this normal stress is directly proportionate to measured normal strain.

The theory presented in this section has provided an appropriate background to the methods a student would have to follow prior to attempting the proposed Normal Stress in Beams Experiment. In addition to calculation of normal strain and stress, the suggestion has been made that the experiment should also provide the user with an accurate display of the maximum beam deflection. Equation 4.13 provides a theoretical method for calculating the maximum deflection in a simply supported beam subject to a concentrated mid-span point load.

$$\delta = \frac{PL^3}{48EI} \tag{4.13}$$

4.6.2 Material Selection

Low carbon (mild) steel has been selected for use on this experiment due to the prevalence of its use in structural and mechanical engineering applications as indicated by Beer and Johnston (2009). As previously demonstrated (refer to Subsection 4.5.2) most steels will not exhibit maximum deflections of the same magnitude as a similar aluminium section. However, of the three proposed experiments, the Normal Stress in Beams Experiment is considered to be the least in need of significant visual deformations. This is supported by inspection of Equation 4.11 which reveals that, providing the section is kept constant, identical levels of normal stress will be generated in a beam regardless of material.

A check of local availability of suitably sized mild steel flat bar revealed a vast array of cross-sections. Table 4.8 provides details of the sections selected for analysis. It has been noted that increasing the width of the section will serve only to increase the maximum load that the section can be subject to prior to yield, maximum deflection remains identical. As a result a material width of 25mm has been nominated.

Table 4.8 - Selection of locally available mils steel flat bars

Size (W x T) (mm)	**Modulus of Elasticity** (GPa)	**Tensile Yield Strength** (MPa)	**Ultimate Tensile Strength** (MPa)
25 x 6	200 (OneSteel 2012)	360 (OneSteel 2012)	480 (OneSteel 2012)
25 x 8	200 (OneSteel 2012)	360 (OneSteel 2012)	480 (OneSteel 2012)
25 x 12	200 (OneSteel 2012)	340 (OneSteel 2012)	480 (OneSteel 2012)

In order to determine the maximum normal stress this steel should be subjected to by the experiments, fatigue calculation must again be performed. These calculations must involve the 100,000 cycle desired life span (refer to Subsection 4.3.3). This process is based on the majority of the descriptions and equations provided in Subsection 4.5.2. $\boldsymbol{S_f}$ for this steel has been calculated at 432 MPa with $\boldsymbol{S_n}$ calculated at 192 MPa.

Now that the both the 10^3 cycle strength $\boldsymbol{S_f}$ and the endurance limit of the materials $\boldsymbol{S_n}$ have been determined the S-N curve can be plotted and the 1×10^5 cycle strength can be graphically determined (refer Appendix I). As with Experiment One, the conservative assumption has been made that the material will be subjected to completely reversed loadings. Results of this analysis have shown the mild steel flat bar has a 1×10^5 cycle endurance limit of approximately 320 MPa. This represents roughly 89% of the tensile yield strength shown in Table 4.8.

Appendix J contains details of a MATLAB script written to theoretically simulate the results of conducting the Normal Stress in Beams Experiment. The script receives a number of inputs and generates required outputs based on the theories presented in Subsection 4.6.1. Inputs include the beam span and material size and properties. Outputs include the maximum load that can be applied and the stress /strain and deflection that will result. Results of running the simulation for the three selected cross-sections are shown in Table 4.9. Note that the maximum normal strain and stress remain unchanged regardless of material geometry.

Table 4.9 - Results of MATLAB simulation - Normal Stress in Beams

Size (W x T) (mm)	**Beam Span** (mm)	**Maximum Load** (N)	**Max. Normal Strain**	**Max. Normal Stress** (MPa)	**Max. Vertical Deflection** (mm)
25 x 6	600	320	0.001602	320.4	- 16.02
25 x 8	600	570	0.001602	320.4	- 12.02
25 x 12	600	1281	0.001602	320.4	- 8.01

From these results the **25x6mm mild steel flat bar** was selected based on the magnitude of maximum deflection it will exhibit whilst exposed to the maximum load of 320 N. This selection clearly ensures fulfilment of Primary Design Objective number five (refer to Subsection 3.2.1).

4.6.3 Primary Component Selection

The final stage of the preliminary design process for experiment three is to specify the suggested hardware required for automation of the apparatus. Primary considerations during this process will be the relevant capacities, availability and the overall physical dimensions. The components to be selected include:

- 1 x Linear actuator
- 1 x Load cell
- 5 x Strain gauges
- 1 x Ultrasonic sensor

Linear Actuator – Subsection 4.6.2 concluded that the selected material (25x6mm FMS) can be subjected to a maximum load of 320 N. As a result it is suggested that that same actuator specified for experiment one (*Linak 23 Techline*) be used on this experiment. This will ensure compliance with ecological consideration number two (refer to Subsection 3.5.2), to design for ease of replacement or updating of components. Appendix I contains a summary of technical specifications for this actuator.

Load Cell – The load cell must be at least capability of withstanding the forces delivered to it by the linear actuator. Given the same linear actuator specified for use on Experiment One has also been specified for load application on the Normal Stress in Beams Experiment, the load cell shall also remain the same. As such, the selected load cell is the *PT4000 universal S-BEAM*. Selected technical specifications of this component have been included in Appendix I.

Strain Gauges – In order to independently determine the amount of normal strain /stress present in the beam it is proposed that a series of five uni-axial strain gauges are attached to the surface of the beam. The strain gauges should be aligned parallel to the beam to directly measure the material strain. Suggested locations for mounting include the centre of the span (max strain), two at a quarter and three-quarters along span respectively and the final two over each of the supports (no normal strain). Results from each of the strain gauges should display a very strong correlation to the theoretical bending moment diagram presented in Subsection 4.6.1.

Ultrasonic Sensor – The ultrasonic sensors required must be capable of high resolution measurement of the beam displacement. Critical to the successful selection of this component will be ensuring the measurement can be taken from the necessary close proximity and the surface of the proposed flat bar. The final selection of this component has also been deemed to be outside the author's expertise and as such must be completed by a technical expert prior to apparatus manufacturing.

4.6.4 Design Outcomes – Shaft Torsion Experiment

This section has successfully detailed the preliminary design process for the Normal Stress in Beams Experiment. The proposed design is seen to have achieved all relevant design ambitions identified in Subsection 4.3.4. Preliminary technical drawings of the experiment are contained in Appendix I. Evidently the design work completed at this point is not to a manufacture-ready stage. Completion of the design to this standard will form part of the suggested future work of this research project. Figure 4.44 demonstrates the results of this design subsystem with key outcomes noted.

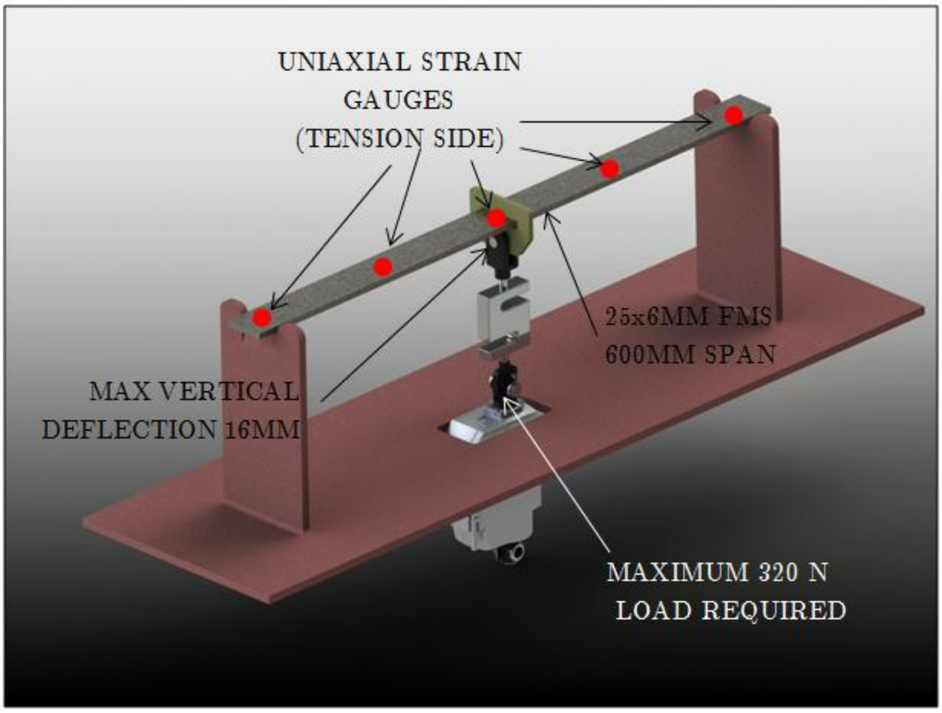


Figure 4.44 - Preliminary design outcomes - Normal Stress in Beams Experiment

4.7 Guarding

The final design requirement of this chapter is to specify the preliminary design of the clear polycarbonate machine guard referred to in Section 1.4. StandardsAustralia (2006) suggest that the design of appropriate safeguarding systems should account for the mechanical hazards involved. The guarding should provide minimal interference with the activities during operation in order to reduce the incentive of evading the safeguard. Figure 4.45 depicts the proposed design without any guarding in place. Clearly this would present a large number of hazards and high level of risk to future users if left unprotected.

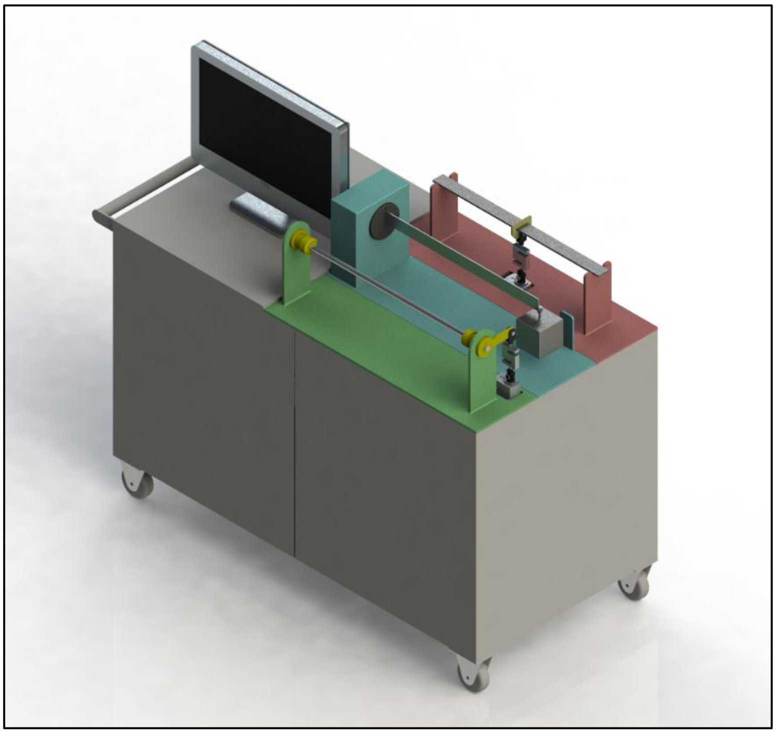


Figure 4.45 - Proposed apparatus design without guards

Based on these risks, a rectangular prism has been selected to totally enclose all three experiments. This is referred to by StandardsAustralia (2006) as a fixed enclosing guard. The material considered most suitable for the construction of this guard is *Safeguard Hard Polycarbonate*. This material is an impact and abrasion resistant polycarbonate sheet which is commonly used for the manufacture of machine guards (Dotmar 2013). A proposed design is shown below.

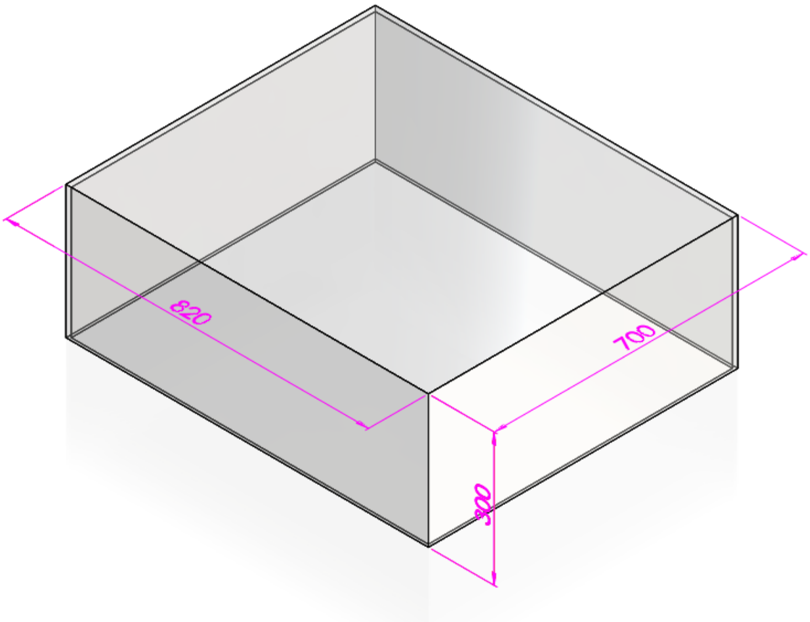


Figure 4.46 - Proposed design of polycarbonate guard

Although this guard will provide users with a very high level of protection from injury whilst in place, StandardsAustralia (2006) indicate that additional safety measures may be required. This is in accordance with the findings of Subsection 3.5.1 (Safety Issues). Section 3.5.1 concluded that the polycarbonate cover must be fitted with an interlock guarding system to insure against accidental operation of the experiments if the guard is removed. An electric safety interlock system is recommended. Selection of this component has been identified as part of the proposed future work of this project.

4.8 Chapter Summary

This chapter has successfully completed the preliminary design of the proposed experimental apparatus in accordance with the material presented in Chapters 1 through 3. Figure 4.47 represents the final design outcome of this research project. Individual design subsystems completed in this chapter have included:

1) Frame
2) Shaft Torsion Experiment
3) Unsymmetric Bending Experiment
4) Normal Stress in Beams Experiment
5) Guarding

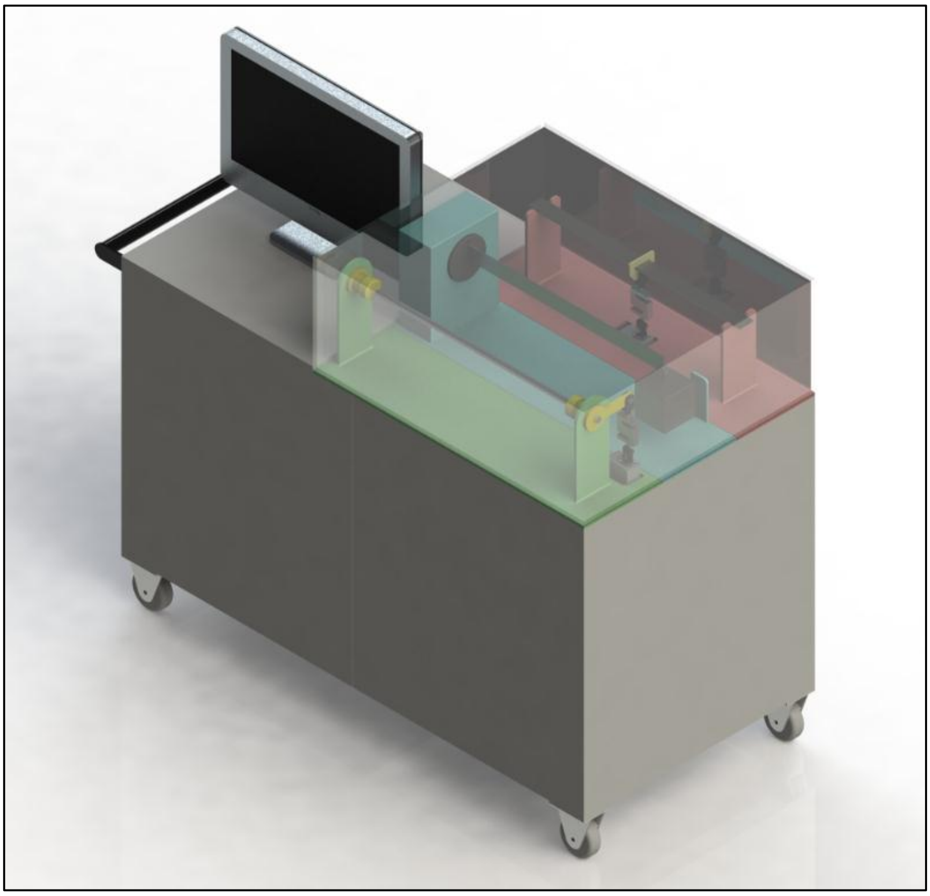


Figure 4.47 - Overview of proposed apparatus design

Chapter 5

Results and Discussion

5.1 Chapter Overview

This chapter presents and discusses the outcomes achieved as a result of this project. Primary topics covered include testing of the three experimental concepts, achieved manufacturing outcomes and an analysis of primary design objective achievement. Chapter 3 of this document provides details of the methodology applied during these processes.

The ultimate project purpose has been to design a physical experimental apparatus intended to enhance the educational outcomes of future MEC2402 students. Considering this, it is clear that the primary project objectives were investigated and presented in the previous chapters. This chapter analyses these design outcomes in an attempt to independently assess and/or validate the attainment of all original project ambitions.

5.2 Summary of Design Achievements

A large amount of design work has been achieved as a result of this project. As such it is seen as important to provide the reader with a brief summary of all design outcomes presented in previous chapters.

Designs for the experiment frame have been completed to a manufacture ready stage. This frame has been designed to be portable and have sufficient space with which to mount the specified touch-screen computer (refer to Subsection 4.2.2) and proposed experiments. The frame is made of 40x40x2.5mm SHS section which is then powder coated satin black. The sheeting material is 16mm thick Laminex™ in the colour *charcoal*. Calculations were performed on the frame design to ensure the strength of the handle, the load capacity of the castors and the maximum deflection that the frame may experience. Results of this analysis confirmed the design.

The preliminary design of the three proposed experiments has been completed with careful consideration for the optimisation of expected educational outcomes. Achievement of this goal was facilitated by the meticulous selection of ten Primary Design Objectives based on the body of literature reviewed in Chapter 2. Each of the three experiments has been specified as using effective beam/shaft lengths of 600mm. Design work completed during this project include:

- Development of three separate MATLAB simulations which predict the behaviour of the experiment when subjected to a given load.
- Specification of the specific metal alloys used for each experiment.
- Specification of the material geometry used on each experiment.
- Preliminary technical drawings of the three experiment designs.
- Analysis of the maximum percent of yield strength the material can be loaded to ensure premature fatigue failure does not occur.
- Determination of the maximum experimental loads.
- Preliminary specification of primary automation and sensory hardware.
- Specification of geometry and the polycarbonate material to be used for guarding manufacture (subject to local availability).

Figures 5.1 shows two identical images of the final project design outcomes. Both images have been annotated with a summary of results.

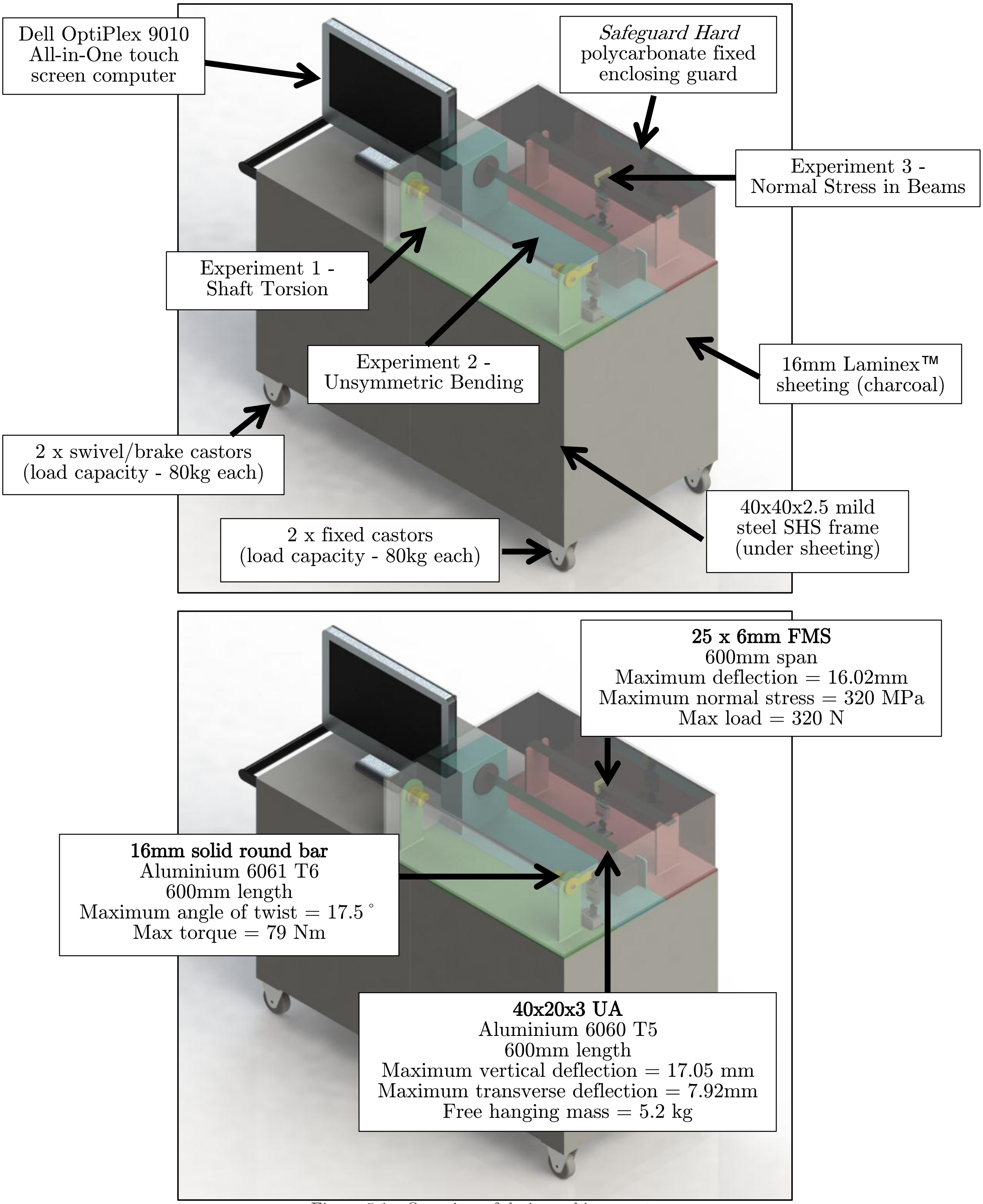


Figure 5.1 - Overview of design achievements

5.3 Testing of Experimental Concepts

Testing of the experimental concepts was performed to ensure the quality of project outcomes in two primary dimensions. Firstly that the theoretical models generated as part of this project are accurate and secondly to gauge the strength of the correlations between theory and practice. The primary limitation during this testing was the certainty with which the magnitude of the applied loads could be determined. To compensate for this uncertainty a tolerance of 5% has been applied to all test results. Testing commenced with the purchase of appropriate length of the three specified materials (see Figure 5.2).

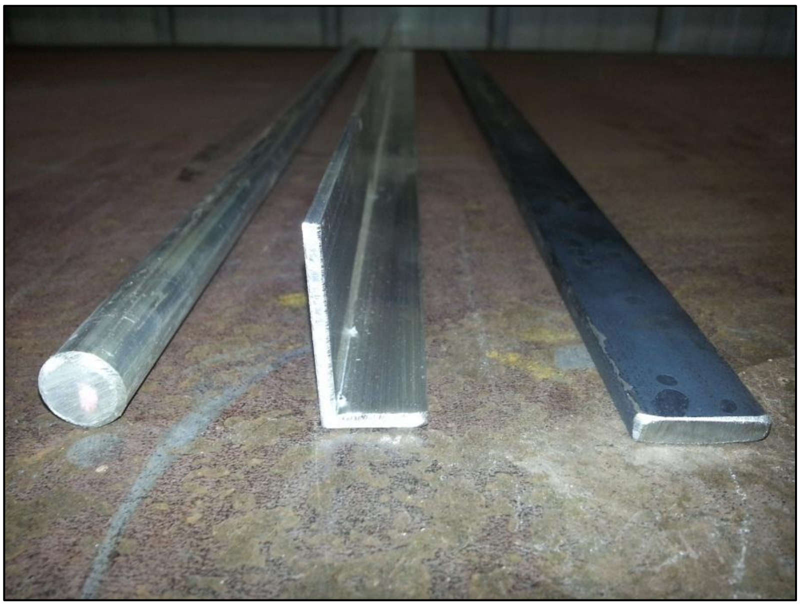


Figure 5.2 - Purchased experimental materials

Each of the materials was then measured to determine the actual size. The results of this are presented and compared to the nominal material sizes in Table 5.1. Vernier calipers were used for this purpose.

Table 5.1 - Measured material sizes vs. nominal material sizes

EXPERIMENT	NOMINAL SECTION SIZE	MEASURED SIZE
1	16mm round	15.76mm
2	40x20x3mm Unequal angle	39.80x19.86x2.89 mm
3	25x6mm Flat bar	25.05x5.96mm

In accordance with the methodology presented in Chapter 3, each of the experiments has been tested using their respective maximum loading scenarios (refer to Chapter 4). Experiment 2 – the Unsymmetric Bending Experiment was tested with an orientation of 45 degrees as opposed to the minimum axes. This procedure ensures appreciable levels of both in-plane and transverse deflections. Table 5.2 summarises the loading scenarios and expected deflections for each experiment.

Table 5.2 - Summary of theoretically predicted results

EXPERIMENT	MATERIAL	SECTION	MAXIMUM LOAD SCENARIOS	PREDICTED DEFLECTION	TOLERANCE Load +- 5%
1	6061 T6 Aluminium	16mm round	78.8 Nm (8.032 kg-m)	17.5 degrees	0.88 deg
2	6060 T5 Aluminium	40x20x3 Unequal angle	5.208 kg	-13.18 mm (y) -6.64 mm (z)	0.66 mm (y) 0.33 mm (z)
3	Mild steel	25x6mm Flat bar	320 N (32.62kg)	16.02 mm	0.8 mm

Based on the measured variations between the nominal material sizes and the actual material sizes, the modified expected results are detailed below. It is important to note that the nominal size results will be used for the primary comparison of with results. This is in accordance with objective 2 of the 2002 ABET Colloquy (refer to Appendix D). The objective states that a fundamental objective of engineering laboratories is to allow students to identify the strengths and limitations of theoretical models as a predictor of real-world behaviour. Theoretical engineering design work is routinely performed based on nominal values. It is important to ensure students understand the relative uncertainty which should be applied to these calculations. Preliminary results of each experimental concept test are included in the following sub-sections 5.3.1 through 5.3.3 with a summary in 5.3.4.

Table 5.3 - Summary of predicted results for nominal and actual material sizes

EXPERIMENT	PREDICTED DEFLECTION - NOMINAL SIZE	PREDICTED DEFLECTION - ACTUAL SIZE	TOLERANCE Load +- 5%
1	17.5 degrees	17.8	±0.88 deg
2	-13.18 mm (y) -6.64 mm (z)	- 13.90 mm (y) - 7.0115 (z)	±0.69 mm (y) ±0.33 mm (z)
3	16.02 mm	16.94 mm	±0.8 mm

5.3.1 Concept Testing – Shaft Torsion Experiment

Testing for this experimental concept involved setting up a jig similar to the proposed experiment design. The fixed end of the shaft was welded to an immovable vertical alumium surface whilst the free end was passed through a 1mm oversized hole in a section of steel angle. A suitable moment arm was then welded to the shaft, 600mm from the fixed end. Finally a second section of angle with an identical hole was then slid and attached over the end of the shaft to minimise any adverse bending effects resulting from the loading scenario.

Although a moment arm of only 100mm was specified in the design (refer to Section 4.4), due to limitation in the scales used, a greater moment arm distance was needed to produce the 78.8 Nm torque required. Results of performing the tests are shown below.

Figure 5.3 – Results of conducting Shaft Torsion concept testing

The loaded angle of twist was measured to be 17.5 degrees. Based on the nominal theoretical value of 17.5 degrees this is considered to be an excellent result. Once the load was removed the shaft returned to its exact original position which clearly demonstrates that no plastic deformation occurred in the shaft.

It is however important to note that the when the moment arm was initially loaded a significant amount of plastic deformation was seen to occur in the weld securing the moment arm to the shaft. As a result it is clear further investigation should be performed into holding methods prior to apparatus manufacture.

5.3.2 Concept Testing Results – Unsymmetric Bending

Testing of the complex unsymmetric bending theory was performed by securing one end of the unequal angle at 45 degrees from the horizontal and applying the 5.2 kg load. This load was applied 600mm from the fixed end of the beam. Considering the results need to be measured in both the vertical and horizontal direction the experiment was performed multiple times. Deflections were calculated by the relative displacement of a dial indicator with and without the applied load.

Figure 5.4 - Results of conducting Unsymmetric Bending concept testing

The loaded deflections were recorded at -16.07 mm along the y direction and -8.08 mm in the z direction. This is noted to be significantly different to the predicted theoretical results of -13.18 mm (y) and -6.64 mm (z). Despite this the results are considered to be valid as the theoretical and practical neutral axis (N.A) orientations share a very close correlation. Theoretical orientation of the neutral axis for this test is shown in Figure 5.5.

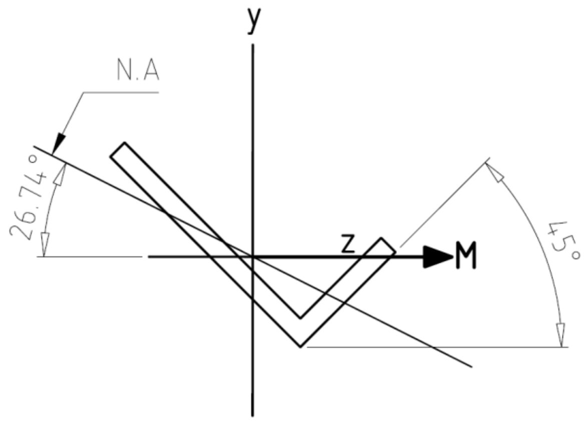
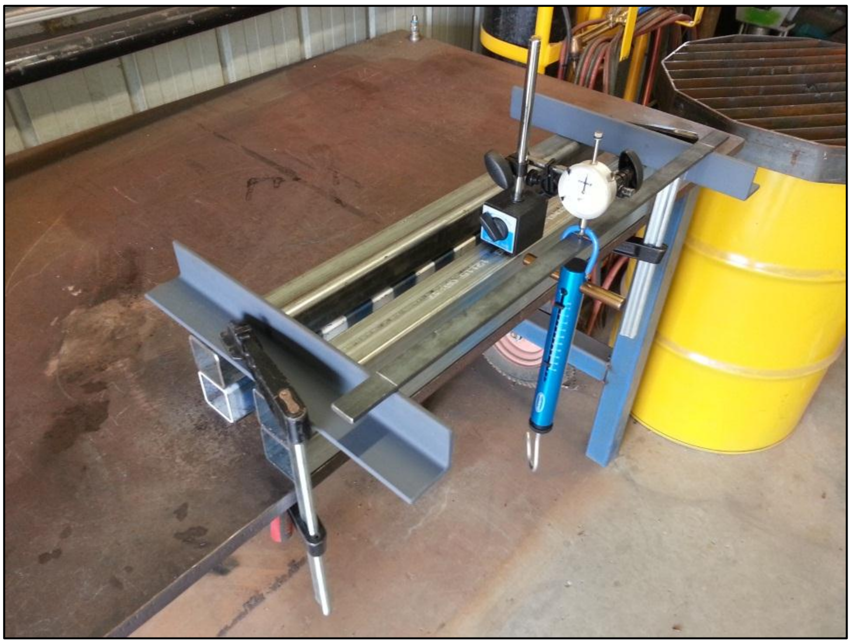


Figure 5.5 - Theoretical N.A. orientation for concept testing

The MATLAB script created for simulating this experiment indicates that the theoretical value of the neutral axis is 26.75 degrees from the horizontal (refer to Appendix J). Analysis of the relative deflections measured during testing indicates that the neutral axis is 26.69 degrees from the same reference point. Clearly this represents a very good result. The variation in deflection values is likely due to either the material having different mechanical properties (principally the modulus of elastic) to those used in Chapter 4 or the applied load was in excess of the specified 5.2 kg. Further testing and material evaluation should therefore be carried out before final manufacture.

5.3.3 Concept Testing Results – Normal Stress in Beams

Concept testing for the Normal Stress in Beams experiment involved the setup of a jig which provided supports for the beam 600mm apart. A load of 32 kg was then centrally applied and measured using a spring balance. Deflections were then calculated from the relative displacements of a dial indicator. Figure 5.6 demonstrates the results of this process.



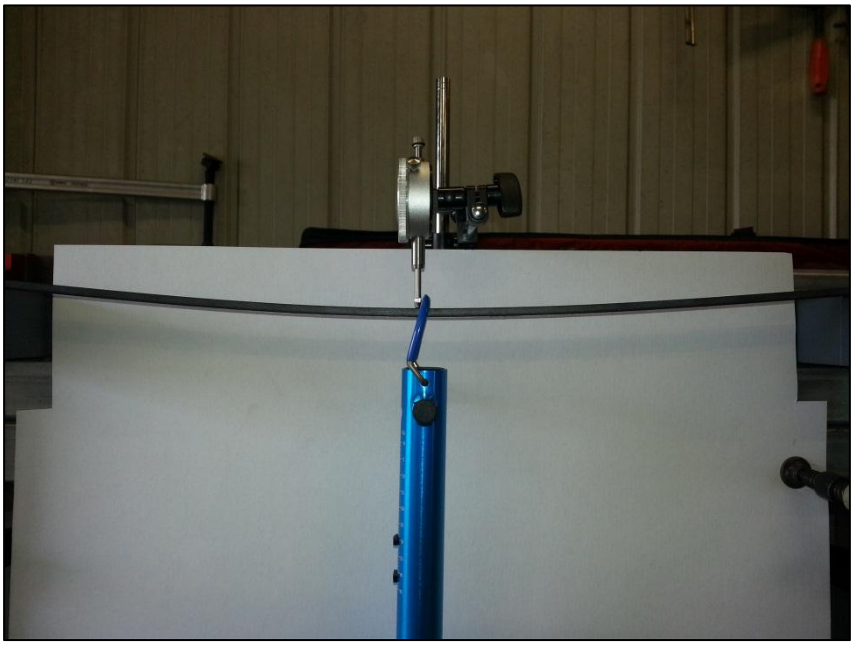


Figure 5.6 – Results of conducting Normal Stress in Beams Concept testing

The results demonstrated an excellent correlation to the theoretical maximum deflection. The measured deflection was 16.57mm as compared to the theoretical 16.02mm. Considering the specified tolerance of 0.8mm, it is clear this result is within the expected range. Once the load was removed the beam returned to the exact initial displacement. The conclusion can therefore be drawn that no plastic deformation occurred during this test. It was also of interest to note that the maximum deflection is particularly clear when viewed from a range of different perspectives.

5.3.4 Summary of Concept Testing Result

Overall the results of the concept test were particularly encouraging. The details are summarised in Table 5.7.

Table 5.4 - Summary of concept testing results

EXPERIMENT	SECTION	LOAD SCENARIO	PREDICTED DEFLECTION	TOLERANCE Load +- 5%	MEASURED DEFLECTION
1	16mm round	8 kg-m Torque	17.5 degrees	±0.88 deg	17.5 degrees
2	40x20x3 Unequal angle	5.2 kg Free hanging load	-13.18 mm (y) -6.64 mm (z)	±0.69 mm (y) ±0.33 mm (z)	- 16.07 mm (y) - 8.08 mm (z)
3	25x6mm Flat bar	32.5 kg Central load	16.02 mm	±0.8 mm	16.57 mm

Experiment 1 (Shaft Torsion) – Results demonstrated an exact correlation between the theory for the nominal size and the measured deflections. Error between the predicted deflection for actual section dimensions was shown to be less than 2%.

Experiment 2 (Unsymmetric Bending) – Although the measured deflections were outside of the specified tolerances this was concluded as being either the result of variation in provided material properties of the actual magnitude of the applied load. The orientation of the neutral axis is neither effected by the load magnitude nor the material properties. As a result the error associated with the theoretical and physically measured values of N.A. was less found to be less than 1%.

Experiment 3 (Normal Stress in Beams) – Concept testing revealed a very strong relationship between theory and measured values of maximum deflection. The results show an error of just over 3% between the theoretically predicted values of 16.02mm and the 16.57mm measured values. It is important to note that this result is within the 5% window of uncertainty with regards to the applied load. A deflection of 16.94mm was theoretical predicted based on the actual material size.

In conclusion, the results of these tests have successfully proved the accuracy of the theoretical models and the correlation between theory and practice. However it remains clear that further testing should be undertaken prior to final apparatus manufacture.

5.4 Achievement of Design Objectives

Section 3.2 outlined a series of ten Primary Design Objectives which were developed in accordance with the findings of the literature review process (Chapter 2) and professional opinions of the MEC2402 Course Examiners. These design ambitions centre primarily on user safety and optimisation of educational merit. Evaluating the achievement of each of these broad aims will form vital conclusions regarding the value of overall project outcomes. It is proposed that all design objectives have been fulfilled during this project.

1) **Comply with limited overall physical dimensions**

   Section 1.4 detailed the requirement for the apparatus design to feature limited overall dimensions to facilitate transportation around campus. The primary consideration was that the apparatus must be able to fit through standard doorways and into elevators. The final design features an overall width of 700mm and a length of 1480mm analysed in Subsection 4.2.3 to be compliant with all requirements.

2) **Design for ease of transport**

   In accordance with Primary Design Objective number two the apparatus (refer to section 1.4) should be designed for ease of transportation around USQ campuses. Subsection 4.2.5 highlights the additions of suitable castors and a handle for controlling the movement of the frame. In addition the mass of the proposed design is deemed to be well within the suitable range of manual handling for one person.

3) **Ensure a strong correlation between physical results and theory**

   Section 5.3 details the result of the experimental concept testing which was performed to ensure compliance with this design objective. The results of this testing demonstrate a very strong correlations between the theoretically calculated values presented in Chapter 4 and physical results.

4) **Achieve high quality results within provided budget**

   Achievement of this design ambition is difficult to formally assess prior to completion of the manufacturing. Despite this it is considered that the proposed design will be highly cost effective owing to the use and specification of locally available materials and technical skills.

5) Design experiments to ensure appreciable visual results

Selection of materials for use on each of the three proposed experiments was made with a primary consideration for the maximisation of the visual results. Aluminium sections were specified for Experiments One and Two primarily specifically due the materials beneficial mechanical properties. Section 5.2 summarises these expected results.

6) Provide all user with a very high level of safety

Completion of a detailed risk assessment (refer to Appendix G and H) identified a number of control measures that were required to ensure achievement of this design objective. Implemented control measures include modification of the frame design to ensure user safety whilst transporting the apparatus. In addition the inclusion of the polycarbonate fixed enclosing guard will ensure users cannot come into contact with any moving parts during experiment operation.

7) Design experiments to appear familiar to students

Attainment of this design objection is considered rather subjective to assess. Despite this, comparison of the images in Subsection 3.2.1 with the design outcome models presented in in Sections 4.4 through 4.6 seem to indicate a level of success in this endeavour.

8) Aim to ensure students trust the authenticity of results

Subsection 3.2.1 indicated that measurement of loads and deflections can be performed from the electrical input to linear actuators. Despite this, the conclusion was drawn that ‘independent’ feedback of these values should be provided to the laboratory user. Specification of independent sensory hardware such as load cells and web cameras was as a direct result of this ambition. Primary Design Objective number eight has therefore clearly been achieved in the design of this apparatus.

9) Experiments should involve materials commonly used in industry

Beer and Johnston (2009) indicate that aluminium and steel are the most common metals used in structural applications. Experiments One and Two have been specified as using standard aluminium alloys while Experiment Three will use mild steel. The material specified for the three experiments have therefore very clearly fulfilled this requirement. All sections are readily available from local metal distributors.

10) Produce an aesthetically effective design

Clearly this is a highly subjective objective to fulfil. It is the personal opinion of the author that the proposed design appears of professional quality. The proposed design is seen, by the author, to be of a standard that will serve to reinforce the USQ brand.

5.5 Manufacturing Outcomes

The manufacture of the proposed frame design has been completed as a result of this project. The following pages briefly highlight the process and outcomes of the manufacture of this component. Manufacture and commissioning of the three proposed experiments will continue beyond the completion of this research project.

The frame was first manufactured from the specified 40x40x2.5mm SHS section in accordance with the technical drawings presented in Appendix I. Following completion of the fabrication process, the frame was powder coated satin black. Laminex™ sheeting, hinges, handles and locks were then fitted to the frame to complete the manufacture. Figures 5.7 through 5.10 detail the results of each of these processes.

Figure 5.7 - Results of frame fabrication process

Figure 5.8 - Results of frame powder coating

Figure 5.9 - Final result of frame manufacture

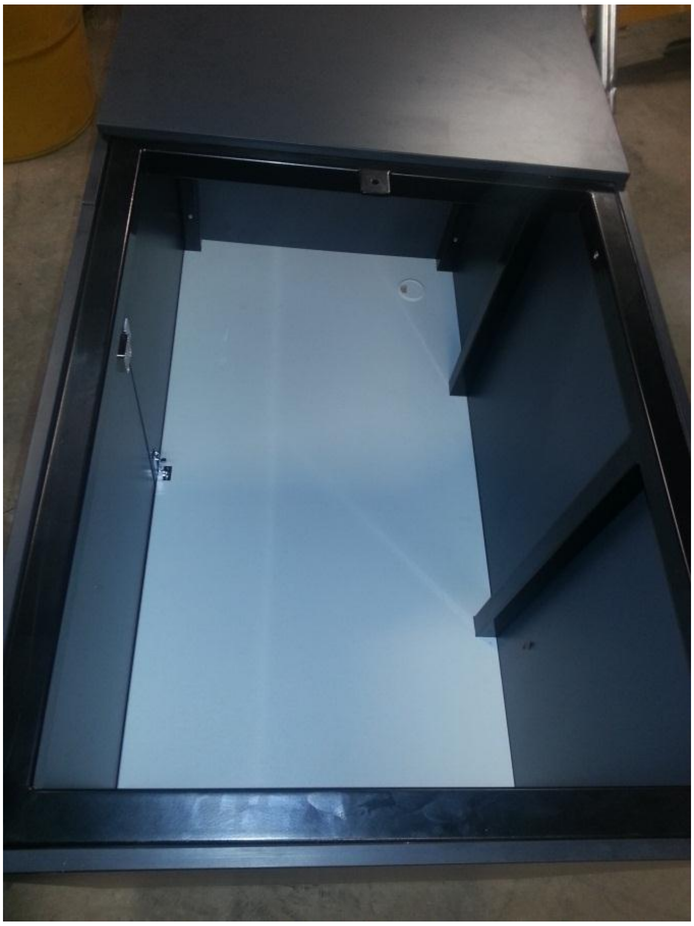


Figure 5.10 - Final result of frame manufacture - inside

5.6 Chapter Summary

This chapter has effectively presented and discussed the outcomes achieved as a result of this project. It is emphasised that the primary ambition of designing a physical experimental apparatus intended to enhance the educational outcomes of future MEC2402 students has been achieved.

Section 5.2 provided a summary of project design achievements, asserting that the designs for the apparatus frame has been completed to a manufacture ready stage. The preliminary design for the three proposed experiments has also been completed to an advanced level. Details of the experimental concept testing were included in 5.3. The primary purpose of these tests was to ensure a strong correlation between the theoretically predicted outcomes with those measured in practice. The results of these tests were shown to be exceptional. The accuracy of the MATLAB simulations generated (refer to Appendix J) to predict experimental results, were therefore also validated in this chapter.

Section 5.4 summarised the achievement of each of the ten Primary Design Objectives (refer to Subsection 3.2.1) and asserted that all have been met as a result of this project. Finally, the project manufacturing results were presented in section 5.5 where it was shown that the manufacture of the final frame has been successfully completed. The final manufacture and commissioning of the completed apparatus is due to continue beyond the completion of this research project.

Chapter 6

Conclusions

6.1 Chapter Overview

This final chapter summarises the achievement of project objectives, identifies future work and provides recommendations. Definitive project conclusions are formed throughout this chapter and formally identified in Section 6.4.

The proposed mechanical design of an experimental apparatus intended for integration in MEC2402 – *Stress Analysis* has successfully been achieved as a direct result of this project. Comprehensive investigation of literature relating to this endeavour indicates the design should ensure optimisation of student learning outcomes. Although complete apparatus design has been completed to an advanced stage, further technical work is required in a number of areas.

Initial aims to complete the manufacture and commissioning of the designed experiment have not been achieved within the research project time frame. Availability of project funding is seen as the primary reason for this outcome. Section 6.2 however, asserts that upon reflection, the original project scope is seen to have been overly ambitious considering the time and resources available. Completion of manufacturing and commissioning is set to continue beyond submission of this dissertation.

6.2 Achievement of Project Objectives

The ultimate purpose of this project has been to design and manufacture a physical experimental apparatus intended to enhance the educational outcomes of future MEC2402 students. Attainment of this core objective has remained dependant on the achievement of four specific core objectives. These are:

1) Fulfilment of the MEC2402 Course Examiners project ambitions
2) Alignment of the apparatus design with the MEC2402 course objectives
3) Fulfilment of identified project Research Objectives
4) Design of the experiments in accordance with findings of an extensive literature review process.

Each of these for objectives is listed below, accompanied by a short summary of achievement relating to the design of this project. It is noted that some objectives share overlapping elements.

1) Section 1.2 detailed the responses of the Course Examiner during a formal interview process. A question relating to which key aspects are considered vital for successful implementation of the laboratory equipment, yielded the following response.

    1. *Safety*
    2. *Accessibility, the capacity for students to personally experiment with the apparatus.*
    3. *Capacity to demonstrate the reliability of theoretical analyses.*
    4. *Integration with relevant coursework (Buttsworth 2013).*

   Safety has clearly been a primary consideration throughout this project. Appendix G & H provide the details of the comprehensive risk assessments undertaken to ensure user safety. Individual user accessibility, regardless of geographical distribution, is assured by the nature of the remote laboratory concept. This was clearly investigated in the project literature review. Reliability of the theoretical analysis was confirmed in Section 5.3. Finally, the specific method with which the experiments are to be integrated into *Stress Analysis* was excluded from the scope of this project in Section 1.6.

2) Section 1.3 discussed the specifics of MEC2402, the course into which the proposed experimental apparatus will be integrated. USQ (2010) provides a list of the primary course objectives. These define the expected student learning outcomes for MEC2402. Objectives are:

1. *Review and apply the principles of static equilibrium to the analysis of structures such as pressure vessels, beams and torsion members.*
2. *Evaluate stress and strain within various structures by applying appropriate engineering theories.*
3. *Formulate solutions to problems requiring the application of suitable engineering theories for stress and strain*
4. *Locate and calculate the highest equivalent stress on any section of a beam or shaft undergoing simple or combined loading, and determine if yield failure will occur*

Comparison of these learning objectives with the project design outcomes presented in Section 5.2, clearly indicates a strong alignment has been achieved.

3) Project research objectives were formally identified in Section 1.7. Primary research objectives have been to:

A. Formally establish the opinions of the MEC2402 Course Examiner with respect to the introduction of an experimental component of the course and how it is believed this will advantage future *Stress Analysis* students

B. Establish whether each of the specific experiments outlined in Section 1.4 can be designed and manufactured on a small scale using commercial automation hardware to provide results that demonstrate a strong correlation with the theory presented in MEC2402.

Objective A was clearly achieved in Section 1.2. The majority of Objective B was achieved during the testing and evaluation phase of this project. The intention was to test the experimental concepts using the specified automation hardware. This was not able to be completed due to the availability of funding. Despite this the results were considered appropriate.

4) Chapter 2 of this document successfully investigated a broad range of available literature relating to the implementation of laboratories in engineering education. Following presentation of the conclusions of Chapter 2, a series of ten Primary Design Objectives were developed. These were generated predominantly to ensure the design of the experiments maximise the student's potential learning outcomes. Section 5.4 highlighted the achievement of all design objectives during this project. As such, it can be concluded that the experiment designs are in accordance with the findings of the literature review process.

Following analysis of each of the four core objectives it is apparent that this research project has fulfilled its ultimate purpose of designing an apparatus to enhance the educational outcomes of future MEC2402 students. It is suggested that the validity of this statement be assessed through analysis of the proposed user perception survey results. Clearly this can only be undertaken once the apparatus is integrated into *Stress Analysis*. Details of this survey are contained in Appendix E.

Unfortunately the complete manufacturing and commissioning of the proposed apparatus was not able to be completed during the time frame of this research project. The original ambition was to complete all detailed design, manufacture, commission and test the remote laboratory apparatus prior to dissertation submission. In reflection, it is apparent that this was a highly ambitious goal. The amount of input required to get the project to its current stage of design, was well in excess of early expectations. As a result, a large amount of work remains to be completed to get the apparatus to a usable stage. This is further discussed in the following section.

6.3 Further Work & Recommendations

Although a significant amount of the original goals have been achieved as part of this research project, a substantial amount of further work remains to complete the project as a whole. Details and recommendations relating to individual items of further project work are listed below.

- **Seek course examiner's approval –** The outcomes of this research project should be presented to the MEC2402 Course Examiner to ensure the approval of the proposed design. Required modifications should be made before progression to any further stages.
- **Further concept testing** - Although the testing of the experimental concepts produced very high quality results. Further material and concept testing should be performed on all three experiments. Future tests must use accurately calibrated measurement equipment to establish a base line for accuracy with which the final experimental results can be compared. Subsection 5.3.1 also identified the need for further mechanical testing of methods of securing the shaft on Experiment One.
- **Final specification of automation hardware –** Chapter 4 completed the preliminary specification of the required mechanical automation hardware. However, the specification of several items was deemed to be outside of the author's expertise during this process. As a result these items must be later specified by a person with suitable technical expertise. Technical approval of all items will also be required prior to purchasing hardware.
- **Complete detailed design of experiments –** Manufacture ready drawings of the three experiments should be completed. Consideration in this process should be given to the outcomes of the final concept testing and automation hardware specification.
- **Finite element analysis (FEA) of experiment bases –** Each of the experiment base designs should be analysed using FEA software to ensure rigidity whilst under load. Excessive deflections have the potential to adversely affect the accuracy of experimental measurements.
- **Complete apparatus manufacture –** Once all required designs have been finalised the complete mechanical assembly of the remote laboratory apparatus can be completed.

A significant amount of work, relating to the project as a whole, must also be achieved once all previously listed 'further work' has been completed. It is important to note that these aspects of the project where eliminated from the scope of this document in Section 1.6. Despite this, further work not directly involved with this document is listed below.

- **Design of electrical control system –** To be completed by external electrical contractors.
- **Electrical wiring** - To be completed by external electrical contractors.
- **Computer interface design –** This will be a particularly important process which has the opportunity to dramatically effect student learning outcomes. Design and optimisation of this interface is seen as a potential student research project for future years.
- **Enable remote access of experiments –** To be completed by USQ ICT.
- **Integrate the apparatus into MEC2402 –** To be completed by MEC2402 academic team.
- **Formal analysis of pedagogical merit –** This project clearly asserts that the proposed experiment design will provide improved educational outcomes for students. It is recognised that this is purely speculative until user perception survey (refer to Appendix E) results are analysed. Only then can the ultimate success of this project be confirmed.

6.4 Conclusion

Laboratory work has long been regarded as an integral component of engineering education, however, the introduction of distance education has complicated this concept. Remote access labs (RAL) allow students to perform experimental investigations without the need to be physically present. MEC2402 - *Stress Analysis* is a large USQ undergraduate engineering course in which typically two-thirds of students study via distance education. *Stress Analysis* is considered to be an academically and conceptually challenging course.

The ultimate purpose of this project has been to design and build a physical RAL experimental apparatus intended to enhance the educational outcomes for future MEC2402 students at USQ. By successfully investigating the relevant pedagogical aspects and mechanical design principals this project has been able to successfully complete the proposed designs of three separate RAL experiments. During this process the majority of originally specified project objectives have been met.

Although further work is required, the outcomes of this project are considered to be particularly positive. If future apparatus users gain just a portion of the appreciation and understanding the author has developed while completing this project, fulfilment of the ultimate purpose is assured.

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Appendix A

Project Specification

University of Southern Queensland

FACULTY OF ENGINEERING AND SURVEYING

ENG4111 – Research Project Part 1

PROJECT SPECIFICATION

FOR: **Scott Cox**

TOPIC: DESIGN AND DEVELOPMENT OF A REMOTE ACCESS EXPERIMENT FOR INTEGRATION INTO MEC2402 – STRESS ANALYSIS

SUPERVISORS: **Ray Malpress**
Les Bowtell

SPONSORSHIP: FOES, USQ (PROPOSED)

PROJECT AIM: This project aims to design and build a number of physical stress analysis experiments (RAL) as proposed through discussions with the MEC2402 course examiner. Project research will focus on the expected pedagogical outcomes of implementing the use of such equipment as well as the optimisation of experiment design to maximise educational benefits to future students.

PROGRAMME: (Issue A, 09 March 2013)

1. Research the use of physical experiments in engineering educational, potentially specifically relating to topics covered in MEC2402.
2. Briefly investigate the background of remote access technology in general and specific to educational applications.
3. Design experiment bench through appropriate investigation of aspects such as:
    a. Desired capability
    b. Safety
    c. Ergonomics
    d. Economic considerations
    e. Component selection
    f. User interface
    g. Expected life span
    h. ...
4. Fabrication and commissioning of the experiment bench. **(July/August)**
5. Assessment of outcomes through feedback studies. Analysis of results.
6. Submission of an academic dissertation on the research, design process and outcomes.

AGREED:__________________(student) __________________(supervisor)

DATE: __________________ __________________

Appendix B

Ethical Approval Documents – Course Examiner Interview

USQ AUSTRALIA	University of Southern Queensland

The University of Southern Queensland
Human Research Ethics Application Form

To complete this form

- The form should be completed electronically. Answers should be given in plain language.
- Click the check boxes were appropriate. Fill in text frames by typing your answers in the space provided underneath the question. The frame will expand to accommodate the text.
- Do not remove/alter formatting

Submission

- Please forward the finalised application including supporting documentation via email to ethics@usq.edu.au. You do not need to forward a hard copy.
- Print the signatures page (last page), arrange signatures and forward to Ethics Officer, ORHD USQ, West St. Toowoomba 4350. QLD, Australia.

NOTE: RESEARCH MUST NOT COMMENCE UNTIL THE APPLICATION HAS BEEN GRANTED ETHICS APPROVAL BY THE UNIVERSITY OF SOUTHERN QUEENSLAND (USQ) HUMAN RESEARCH ETHICS COMMITTEE (HREC)

1. GENERAL INFORMATION

Title of project	Design of Remote Laboratory Experiments for Integration into MEC2402 – Stress Analysis

Applicant details:

Name of applicant	Scott Cox
Faculty/School/Section	Faculty of Health, Engineering and Sciences
Campus	Toowoomba
Postal Address	N/A
Email	scott.cox@outlook.com
Telephone	0439 967 011
Purpose of Research	☐ USQ staff research ☒ Student research, *please name the degree(s) the research will contribute to:* Bachelor of Engineering (Mechanical)

Supervisor details (if applicable):

Name of supervisor	Ray Malpress
Faculty/School/Section	Computational Engineering and Science Research Centre
Campus	Toowoomba
Postal Address	N/A
Email	ray.malpress@usq.edu.au
Telephone	+61 7 4687 3873

Additional research team members (if applicable):

Please name the investigator and their organisation/employer *Press 'enter' to add more investigators*	1. Scott Cox 2. 3.

Proposed dates of data collection: *This will be the dates clearance is given for inclusive. Clearance is provided for a max. 3 years*	Start: 06/09/13	End: 13/09/13

Status of funding/support for the project:	☐ Unfunded ☐ Funding pending ☒ Funding received

	If the project is funded, briefly describe the name of the funding organisation and the title of the grant application.
	Learning and Teaching Performance Fund - USQ

2. PROJECT DETAILS
2.1 Plain language statement of project *Using "lay language", provide a brief summary of the project (300 words max) outlining the project's broad aims, participant group(s), and possible outcomes.* The ultimate purpose of this project is to design and manufacture a physical experimental apparatus intended to enhance the educational outcomes for students undertaking the course 'Stress Analysis' at the University of Southern Queensland (USQ). This project is being conducted as part of a final year student research project.
2.2 Research Categories *Please mark as many categories as are relevant to the proposed research* ☐ Anonymous questionnaire/survey (Participants are not personally identified and cannot be re-identified from collected data) ☐ Coded (potentially identifiable) questionnaire/survey ☒ Identified questionnaire/survey ☐ Examination of student work, educational instructional techniques etc. ☐ Examination of medical, education, personnel or other confidential records ☐ Observation (overt – with participant's knowledge) ☐ Observation (covert – without participant's knowledge) ☐ Focus groups ☒ Interviews (structured or unstructured) ☐ Telephone interviews ☐ Procedures involving physical experiments (e.g. exercise) ☐ Procedures involving administration of substances (e.g. drugs, alcohol, food) ☐ Physical examination of participants (e.g. blood glucose, blood pressure and temperature monitoring) ☐ Surgical procedures ☐ Recordings (video) ☐ Recordings (audio) ☐ Other:
2.3 Research Methodology *Outline the proposed method, including data collection techniques and instruments, tasks participants will be asked to complete, estimated time commitment required of them, and how data will be analysed (300 words max).* It is proposed that the current Course Examiner for MEC2402 (Stress Analysis) be provided with a series of 6 short questions (written) relating to his professional views of introducing a laboratory element into the course. The participant is required to complete a short written answer to each question and return responses to the student via email. It is expected that total time commitment for this process will be approximately 1 hour. Development of the laboratory equipment was originally proposed by the Course Examiner and the interview questions seek to formally document his views for inclusion in the student's thesis.

3. PARTICIPANTS AND RECRUITMENT		
Section 4 of the National Statement on Ethical Conduct in Human Research has identified particular groups of research participants which require special ethical consideration. These groups include: ***pregnant women and the foetus*** *(Ch 4.1);* ***children and young people*** *(Ch 4.2);* ***people in dependent or unequal relationships*** *(Ch 4.3);* ***people highly dependent on medical care*** *(Ch 4.4);* ***people with cognitive impairment, intellectual disability, or mental illness*** *(Ch 4.5);* ***people involved in illegal activities*** *(Ch 4.6);* ***Aboriginal and Torres Strait Islander peoples*** *(Ch 4.7);* ***people in other countries*** *(Ch 4.8);* ***other cultural and ethnic groups.*** *Researchers are obliged to ensure they protect the interests of these groups if they are in any way involved in a project, and are therefore advised to investigate thoroughly how these special groups may or may not be involved in, or represented in, the project and to consider if there might be an adverse effect on members of these groups if they are involved in or represented in the project.* *If participation of any of the above-listed groups is a focus of your research, your ethics application will* ***not*** *qualify for review through the Fast Track process.*		
3.1 Participants *Please provide detail on the group and source of potential participant(s).* *Current MEC2402 (USQ) Course Examiner*		
3.2 Expected age(s) of participant(s) – please mark one or more ☐ Children (under 14) ☐ Young people (14-18) ☒ Adults (> 18)		
3.3 Expected number of participant(s) *If the research has several stages and/or groups of participants, please provide the total number of participants expected as well as the number and participant group involved in each stage.* 1 participant		
3.4 How will potential participants in your research be recruited? *Please provide detail on:* • *how contact will be made with participants (i.e. personal approach, email, through an organisation, advertisements, mail out);* • *who will be involved in the recruitment of participants;* • *"gate-keeper" approvals and evidence of same, ie approval or permission from a person representing an organisation which gives permission for the researcher to access participants under their authority. For eg a Principal of a particular school may be an authorised person from Education Qld providing authority for a researcher to interview teachers or students from that school.* Solely as a result of the participant's position as MEC2402 Course Examiner.		
3.5 List the location(s) where the data will be collected P10 – USQ Toowoomba		
3.6 Does this research involve recruitment through an organisation other than USQ? If YES, • please list the organisations; and • Specify whether you have obtained written permission from the organisation to recruit the participants.	**Yes** ☐	**No** ☒

3.7 Does this research involve USQ staff, students or data?	Yes	No
If YES, • please list the relevant faculties/school/section; and • specify whether you have obtained written permission to recruit USQ students and provide documentary evidence of the approval given MEC2402 Course Examiner	☒	☐

4. RISKS AND BENEFITS

4.1 Please indicate any potential <u>risks</u> to participants, researchers and/or others connected with the proposed project. Please tick the appropriate risk category and elaborate in 4.3-4.5.

A risk is a potential form of harm, discomfort or inconvenience.

☐ Physical risks
  ☐ *to the participant/s*
  ☐ *to the researcher/s*
☐ Social risks
☐ Time imposition
☐ Other risks (please explain in the space provided below)
☒ No risks

4.2 Indicate what you think is the overall level of risk for prospective participants:

☐ extreme risk
☐ high risk
☐ some risk
☒ low risk
☐ no foreseeable risk associated with the project

Explain why have you indicated this level of risk?

The research is merely documenting a USQ staff member's professional opinion which is openly shared.

4.3 Please explain your assessment of the risks associated with the research, giving details of the ethical considerations attached to the proposed project.

The project/thesis within which the results of this research will be included has conducted an ethical review in accordance with the Engineers Australia Code of Conduct. No ethical concerns relating specifically to this process were identified.

4.4 Please justify the study in terms of the risk to participants.

Give your assessment of how the potential benefits to the participants or contributions to the general body of knowledge would outweigh the risks.

Considering the purpose of this project is to design and manufacture a laboratory apparatus intended to improve the educational outcomes of USQ students and there is a very low risk to the participant, the study is clearly justified.

4.5 How will any potential risks be minimised and/or managed?

Continual review during study process

4.6 For physiological studies – is exposure to bodily fluids e.g. blood, likely to occur?
Please also provide detail on the precautions to avoid exposure and the measures to be undertaken if exposure occurs. Consult the 'Guidelines for the prevention of transmission of infectious diseases' for more information.

N/A

4.7 Detail the expected benefits of the study to the participants and/or the wider community.

Benefit to participant – Formal documentation of professional opinions. In addition the study will contribute towards realising the participant's ambition of including a laboratory element into a previously theoretical course.

Wider community – Future USQ engineering students will have access to improved educational opportunities during their studies

5. CONSENT PROCESS

5.1 How will consent for participation be obtained?
For each of the research categories identified in Question 2.2 please indicate whether consent will be obtained by:

- writing
- verbally
- tacit (e.g. indicated by completion and return of survey – only for anonymous surveys)
- other
- consent not being sought (explain why)

Written – Consent Form
Written - Through participants participation in study

	Yes	No
5.2 Is it anticipated that all participants will have the capacity to consent to their participation in the research? If NO, please explain why not (e.g. children, incompetent participants, etc.) and explain how proxy or substitute consent will be obtained from the person with legal authority to consent on behalf of the participant.	☒	☐
5.3 Does the research <u>specifically</u> target the following groups of participants: • minors (under 18 years) • Aboriginal and Torres Strait Islander Peoples • people from non-English speaking backgrounds • people with an intellectual impairment or a mental illness • prisoners • people who may be involved in illegal activities • people in dependent relationships with the researcher, institution or funding body (i.e. researcher's clinical clients or students; employees of the institution; recipients of services provided by the funding body) • any other vulnerable group of participants	☐	☒

5.4 If you have answered <u>yes</u> in question 5.3, please provide details of: • the group of participants • how the research participants' rights will be protected • how you will be sensitive to cultural backgrounds (if applicable). N/A
5.5 How does the consent process ensure that informed consent is freely obtained from participants? *Please detail* Both through the completion of the participant consent form and the returning of email with response to study in the participants own time.
5.6 How does the project address the participant(s) freedom to discontinue participation? Will there be any adverse effects on participants if they withdraw their consent? *Please detail* The participant has a specific interest in the student project and is well aware of the role he is to play in its completion. They will be no major adverse effects if the participant withdraws from the study.
5.7 Will participants be able to withdraw data concerning themselves if they withdraw their consent to participate? *Please detail* Yes, should the participant wish to withdraw his responses to this study this can be done through contacting the 'researcher'. This option will be available until thesis submission on the 24th October 2013

5.8 Does the project involve withholding relevant information from participants or deceiving them about some aspect of the research? If YES, please justify	**Yes** ☐	**No** ☒
5.9 Will participants be offered reimbursements, payments or incentives to participate in the research? If YES, what is the amount/benefit and the justification for this?	**Yes** ☐	**No** ☒

6. DEBRIEF AND FEEDBACK
6.1 Will participant(s) be debriefed at the completion of the research? *Please also include details of agencies to which participants may be referred if they become distressed by the procedures (if applicable).* Yes, the participant is to be updated throughout completion of the project.
6.2 Will feedback/summary of results be made available to participant(s)? *If feedback is available, please explain the process for providing the information and how participant confidentiality will be maintained.* Yes, Completed thesis will be provided to participant prior to submission for review.

7. CONFIDENTIALITY AND STORAGE

7.1 Collection of data: Please indicate in what form personal information will be collected.
Personal information means information, or an opinion, that can be part of a database, whether true or not and whether recorded in a material form or not, about an individual whose identity is apparent or can reasonably be ascertained from the information or opinion.

☒ Identified
☐ De-identified
☐ Re-identifiable/coded
☐ No personal information will be collected

Additional information, provide here:

7.2 Storage of data: Please indicate in what form personal information will be stored.

☒ Identified
☐ De-identified
☐ Re-identifiable/coded
☐ No personal informatio will be collected

Additional information, provide here:

7.3 Publication/reporting of data: Please indicate in what form personal information will be published/reported.

☐ Identified
☐ De-identified
☐ Re-ident fiable/coded
☒ No personal information will be published

Additional information, provide here:

7.4 Describe the procedures that will be adopted to ensure confidentiality of participant(s) during the collection of the data, in the storage of the data, and in the publication of results.

Participant name or personal details will not be included in student's thesis.

7.5 Will a recording (audio, video, photograph or other) of participants be made? If so, what purpose will this recording be used for? Will it be retained and used beyond the initial transcription/analysis or will it be erased following transcription?

N/A

	Yes	No
7.6 Will the data be stored for the requisite 5 years (or 15 years for clinical research) and then destroyed? If NO, please justify	☒	☐

7.7 Give details of the arrangements for safe storage of data (e.g. locked filing cabinet, password protected computer)

(a) during the study

Password protected computer

(b) after completion of the study

Password protected computer

7.8 For physiological studies – are provisions made for the participant(s) and his/her usual medical attendant to be informed of information obtained throughout the research? What steps will be taken to ensure that the relationships between participant(s) and their usual medical attendants are not adversely affected by the research, and confidential relationship(s) between doctor(s) and patient(s) are preserved? N/A

8. PRIVACY		
8.1 Does this project involve obtaining identifiable information (e.g. data) from a third party without prior consent from the participant(s) or their legal guardian(s)?	**Yes** ☐	**No** ☒
8.2 Will the research involve access to identifiable personal information (e.g. contact lists) held by another agency/body subject to the Privacy Act 1988 (Cth) or Public Health Act 2005 (QLD)? If YES, outline the measures to obtain *prior* consent from the identified individuals, or the procedures to address the regulatory privacy considerations (please contact the Ethics Officer for guidance). If the exemption under s95/s95A of the Privacy Act is to be sought please contact the Ethics Officer.	**Yes** ☐	**No** ☒

9. CHECKLIST: Have the following (where applicable) been attached to this application?	
Anonymous survey	☐ Survey ☐ Participant Information Sheet
Identified survey	☐ Survey ☐ Participant Information Sheet ☐ Consent Form
Interview/focus groups	☒ Sample questions ☐ Participant Information Sheet ☐ Consent Form
Other method (where applicable)	☐ Instrument ☐ Participant Information Sheet ☒ Consent Form
Advertisements/letters of invitation (where applicable)	☐ Yes ☐ N/A
Evidence of permission from external organisation to conduct research and/or recruit participants (e.g. School or Hospital)	☐ Yes ☐ Currently being sought ☐ N/A
Evidence of permission from USQ to recruit USQ students	☐ Yes ☐ Currently being sought ☐ N/A
Other, please describe	

SUBMISSION

1) Please forward the finalised application including supporting documentation via email to ethics@usq.edu.au. You do not need to forward a hard copy.
2) Print the signatures page (last page), arrange signatures and forward to Ethics Officer, ORHD USQ, West St. Toowoomba 4350. QLD, Australia.

SIGNATURES PAGE

Title of project	Design of Remote Laboratory Experiments for Integration into MEC2402 – Stress Analysis

Applicant declaration

I the undersigned confirm that the information contained in this application is accurate; conduct will not commence until ethical certification has been granted; all members of the research team will conduct this project in accordance with the principles contained in the National Statement on Ethical Conduct in Human Research (2007); will comply with any other condition laid down by the University of Southern Queensland Human Research Ethics Committee.

[signature]	Scott Cox	05 / 09 / 2013
Signed	Print name	Date
		/ /
Signed	Print name	Date
		/ /
Signed	Print name	Date
		/ /
Signed	Print name	Date
		/ /
Signed	Print name	Date

Supervisor declaration (if applicable)

I have been involved in the preparation of this application and agree with the information it contains.

[signature]	RAY MALPRESS	5 / 9 / 13
Signed	Print name	Date

PROPOSED INTERVIEW QUESTIONS

1) Describe the factors which resulted in the inception of this project.

2) Based on your past academic teaching experience do you believe students benefit from exposure to laboratory experiments and demonstrations?

3) Describe the effectiveness of the implementation of the existing experimental rig in the 2013 offering of the course.

4) With respect to apparatus design, what key aspects would you consider vital to the successful implementation of laboratory equipment?

5) Briefly describe the reasoning behind the selection of the three proposed experiments.

6) What do you hope to gain through the use of remote access technology?

University of Southern Queensland

The University of Southern Queensland

Participant Information Sheet

HREC Approval Number:

Full Project Title: **Design of Remote Laboratory Experiments for Integration into MEC2402 - Stress Analysis**

Principal Researcher: Scott Cox

Other Researcher(s): Scott Cox

I would like to invite you to take part in this research project.

1. Procedures

Participation in this project will involve

- ***Providing you with a series of 6 written questions relating to your professional view towards this project.***
- ***You will be required (should you choose) to provide a short email response to each question and return to researcher.***

2. Voluntary Participation

Participation is entirely voluntary. **If you do not wish to take part you are not obliged to.** If you decide to take part and later change your mind, you are free to withdraw from the project at any stage. Any information already obtained from you will be destroyed.

Your decision whether to take part or not to take part, or to take part and then withdraw, will not affect your relationship with the University of Southern Queensland.

Please notify the researcher if you decide to withdraw from this project.

Should you have any queries regarding the progress or conduct of this research, you can contact the principal researcher:

Scott Cox
Bachelor of Engineering (Mechanical) - Student
Faculty of Health, Engineering and Science
0439 967 011

If you have any ethical concerns with how the research is being conducted or any queries about your rights as a participant please feel free to contact the University of Southern Queensland Ethics Officer on the following details.

Ethics and Research Integrity Officer
Office of Research and Higher Degrees
University of Southern Queensland
West Street, Toowoomba 4350
Ph: +61 7 4631 2690
Email: ethics@usq.edu.au

USQ

AUSTRALIA

University of Southern Queensland

The University of Southern Queensland

Consent Form

HREC Approval Number:

TO: Participant - MEC2402 Course Examiner

Full Project Title: **Design of Remote Laboratory Experiments for Integration into MEC2402 - Stress Analysis**

Principal Researcher: Scott Cox

Student Researcher: Scott Cox

Associate Researcher(s):

- The nature and purpose of the research project has been explained to me. I understand and agree to take part.
- I understand the purpose of the research project and my involvement in it.
- I understand that I may withdraw from the research project at any stage and that this will not affect my status now or in the future.
- I understand that while information gained during the study may be published, I will not be identified and my personal details will remain confidential.

Name of participant...[redacted]......................

Signed......[redacted] **Date**....24/9/13...

If you have any ethical concerns with how the research is being conducted or any queries about your rights as a participant please feel free to contact the University of Southern Queensland Ethics Officer on the following details.

Ethics and Research Integrity Officer
Office of Research and Higher Degrees
University of Southern Queensland
West Street, Toowoomba 4350
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USQ
AUSTRALIA

University of Southern Queensland
TOOWOOMBA QUEENSLAND 4350
AUSTRALIA
TELEPHONE +61 7 4631 2300
CRICOS: QLD 00244B NSW 02225M

www.usq.edu.au

OFFICE OF RESEARCH AND HIGHER DEGREES
Ethics Committee Support Officer
PHONE (07) 4631 2690 | FAX (07) 4631 1995
EMAIL ethics@usq.edu.au

Scott Cox
C/- Faculty of Health, Engineering and Sciences
TOOWOOMBA QLD 4350

Dear Scott,

The Chair of the USQ Fast Track Human Research Ethics Committee (FTHREC) recently reviewed your responses to the FTHREC's conditions placed upon the ethical approval for the below project. Your proposal now meets the requirements of the *National Statement on Ethical Conduct in Human Research (2007)* and full ethics approval has been granted.

Approval No.	**H13REA223**
Project Title	Design of remote laboratory experiments for integration into MEC2402- stress analysis
Approval date	04 October 2013
Expiry date	04 March 2014
FTHREC Decision	**Approved**

The standard conditions of this approval are:

(a) conduct the project strictly in accordance with the proposal submitted and granted ethics approval, including any amendments made to the proposal required by the HREC
(b) advise (email: ethics@usq.edu.au) immediately of any complaints or other issues in relation to the project which may warrant review of the ethical approval of the project
(c) make submission for approval of amendments to the approved project before implementing such changes
(d) provide a 'progress report' for every year of approval
(e) provide a 'final report' when the project is complete
(f) advise in writing if the project has been discontinued.

For (c) to (e) forms are available on the USQ ethics website: http://www.usq.edu.au/research/ethicsbio/human

Please note that failure to comply with the conditions of approval and the *National Statement (2007)* may result in withdrawal of approval for the project.

You may now commence your project. I wish you all the best for the conduct of the project.

AJackson

Annmaree Jackson
Ethics Committee Support Officer

Copies to: scott.cox@outlook.com
ray.malpress@usq.edu.au

Appendix C

Stress Analysis – Student Data

This appendix provides details of data obtained relating to student participation in MEC2402 in previous years. Summaries of this data are presented in Section 1.3 with the purpose of providing the reader with some perspective of the course with which this project aims to benefit. All data was provided by the MEC2402 Course Examiner.

Table B1 summarises all student participation and results MEC2402 since 2009. It is important to note the last four columns in the table which depict students who did not pass the course for the following reasons:

FNC, Fail Not Complete – Student did not complete all assessment items.

FNP, Fail Not Participate – Student did not participate in any assessment item.

FNS, Fail Not Sit – Student did not sit final exam.

OTHER – Includes students receiving incomplete results such as those requiring to submit differed assignments or sit supplementary exams in following years in order to receive a passing grade.

Table B1 - Data relating to student participation and results in MEC2402

YEAR	STUDY MODE	NUMBER OF STUDENTS	PASSING GRADES %				FAILING GRADES %				OTHER
			HD	A	B	C	F	FNC	FNP	FNS	
2009	ON-CAMPUS TOOWOOMBA	74	33.8	21.6	12.1	17.6	1.4	0	1.4	2.7	9.4
	ON-CAMPUS SPRINGFIELD	6	33.3	33.3	16.7	16.7	0	0	0	0	0
	EXTERNAL	132	19.7	18.9	18.2	18.2	9.1	0.8	3.8	4.5	6.8
2010	ON-CAMPUS TOOWOOMBA	57	8.8	22.8	19.3	31.6	8.9	3.5	1.7	0	3.4
	ON-CAMPUS SPRINGFIELD	7	0	14.3	14.3	28.5	14.3	0	14.3	0	14.3
	EXTERNAL	159	4.4	8.8	17.6	28.3	20.7	4.4	3.8	4.4	7.6
2011	ON-CAMPUS TOOWOOMBA	76	10	12	12	34	18	2.6	2.6	4	4.8
	ON-CAMPUS SPRINGFIELD	10	10	10	10	40	10	0	0	10	10
	EXTERNAL	170	0.6	4.7	14.7	47	13	2.4	2.4	7.7	7.5
2012	ON-CAMPUS TOOWOOMBA	60	10	11.6	15	45	13.3	1.6	0	3.3	0
	ON-CAMPUS SPRINGFIELD	14	7.1	28.6	28.6	21.4	14.3	0	0	0	0
	EXTERNAL	146	7.5	10.3	23.3	43.2	6.2	2.1	2.7	4.1	0
2013	ON-CAMPUS TOOWOOMBA	76	9.2	17.1	28.9	25	3.9	9.2	6.6	0	0
	ON-CAMPUS SPRINGFIELD	12	0	8.3	33.3	50	0	0	0	8.3	0
	EXTERNAL	141	2.8	8.5	27	42.6	5	6.4	2.8	5	0

In order to draw a comparison between the average results achieved in MEC2402 and other USQ engineering courses it is necessary to remove all students from the supplied data who did not receive HD, A, B, C or F. Table B2 shown over the page summarises this reduced number of students and the percentage distribution of each grade achieved.

Table B2 - Distribution of grades amongst students

YEAR	STUDY MODE	NUMBER OF STUDENTS	GRADES %				
			HD	A	B	C	F
2009	ON-CAMPUS TOOWOOMBA	64	39.1	25.0	14.0	20.3	1.6
	ON-CAMPUS SPRINGFIELD	6	33.3	33.3	16.7	16.7	0.0
	EXTERNAL	111	23.4	22.5	21.6	21.6	10.8
2010	ON-CAMPUS TOOWOOMBA	52	9.6	24.9	21.1	34.6	9.7
	ON-CAMPUS SPRINGFIELD	5	0.0	20.0	20.0	39.9	20.0
	EXTERNAL	127	5.5	11.0	22.1	35.5	25.9
2011	ON-CAMPUS TOOWOOMBA	65	11.6	14.0	14.0	39.5	20.9
	ON-CAMPUS SPRINGFIELD	8	12.5	12.5	12.5	50.0	12.5
	EXTERNAL	136	0.8	5.9	18.4	58.8	16.3
2012	ON-CAMPUS TOOWOOMBA	57	10.5	12.2	15.8	47.4	14.0
	ON-CAMPUS SPRINGFIELD	14	7.1	28.6	28.6	21.4	14.3
	EXTERNAL	132	8.3	11.4	25.7	47.7	6.9
2013	ON-CAMPUS TOOWOOMBA	64	10.9	20.3	34.4	29.7	4.6
	ON-CAMPUS SPRINGFIELD	11	0.0	9.1	36.4	54.6	0.0
	EXTERNAL	121	3.3	9.9	31.4	49.6	5.8

By calculating the total number of students achieving each grade across the three methods of course delivery the overall grade distribution can be ascertained. This data is present in Table B3 below. Note that the results recorded in 2009 appear to be significantly dissimilar to results of the following years; as such this data has been discounted for the purpose of establishing the average distribution of grades. The final Table B.4 simply provides a summary of the average number of total MEC2402 student participates.

Table B3 - Average distribution of MEC2402 grades from provided data

YEAR	OVERALL GRADING %				
	HD	A	B	C	F
~~2009~~	~~29.3~~	~~23.7~~	~~18.8~~	~~21.0~~	~~7.2~~
2010	6.5	15.2	21.7	35.3	21.2
2011	4.6	8.6	16.8	52.4	17.6
2012	8.8	12.8	23.2	45.8	9.4
2013	5.6	13.3	32.7	43.4	5.1
AVERAGE	6.4	12.5	23.6	44.2	13.3

Table B4 - Summary of total student participation in MEC2402 since 2009

YEAR	EXTERNAL STUDENTS	ON-CAMPUS STUDENTS	TOTAL NUMBER OF STUDENTS
2009	132	80	212
2010	159	64	223
2011	170	86	256
2012	146	74	220
2013	141	88	229
AVERAGE	149.6	78.4	228

Appendix D

2002 ABET Colloquy – Laboratory Objectives

The following was taken from (Feisel & Rosa 2005).

The Fundamental Objectives of Engineering Instructional Laboratories

All objectives start with the following: "By completing the laboratories in the engineering undergraduate curriculum, you will be able to…."

Objective 1: Instrumentation. Apply appropriate sensors, instrumentation, and/or software tools to make measurements of physical quantities.

Objective 2: Models. Identify the strengths and limitations of theoretical models as predictors of real-world behaviors. This may include evaluating whether a theory adequately describes a physical event and establishing or validating a relationship between measured data and underlying physical principles.

Objective 3: Experiment. Devise an experimental approach, specify appropriate equipment and procedures, implement these procedures, and interpret the resulting data to characterize an engineering material, component, or system.

Objective 4: Data Analysis. Demonstrate the ability to collect, analyze, and interpret data, and to form and support conclusions. Make order of magnitude judgments and use measurement unit systems and conversions.

Objective 5: Design. Design, build, or assemble a part, product, or system, including using specific methodologies, equipment, or materials; meeting client requirements; developing system specifications from requirements; and testing and debugging a prototype, system, or process using appropriate tools to satisfy requirements.

Objective 6: Learn from Failure. Identify unsuccessful outcomes due to faulty equipment, parts, code, construction, process, or design, and then re-engineer effective solutions.

Objective 7: Creativity. Demonstrate appropriate levels of independent thought, creativity, and capability in real-world problem solving.

Objective 8: Psychomotor. Demonstrate competence in selection, modification, and operation of appropriate engineering tools and resources.

Objective 9: Safety. Identify health, safety, and environmental issues related to technological processes and activities, and deal with them responsibly.

Objective 10: Communication. Communicate effectively about laboratory work with a specific audience, both orally and in writing, at levels ranging from executive summaries to comprehensive technical reports.

Objective 11: Teamwork. Work effectively in teams, including structure individual and joint accountability; assign roles, responsibilities, and tasks; monitor progress; meet deadlines; and integrate individual contributions into a final deliverable.

Objective 12: Ethics in the Laboratory. Behave with highest ethical standards, including reporting information objectively and interacting with integrity.

Objective 13: Sensory Awareness. Use the human senses to gather information and to make sound engineering judgments in formulating conclusions about real-world problems.

Appendix E

User Perception Survey - Proposed

PROPOSED USER PERCEPTION SURVEY FOR ANALYSIS OF MEC2402 RAL APPARATUS EFFECTIVENESS (PAGE 1 of 2)

This proposed survey is intended to be integrated into the user interface of the completed MEC2402 RAL apparatus. It is suggested that an option to undertake the survey will be provided to users once they have completed an investigation on one or all of the three experiments. User perceptions should be obtained through both qualities and quantities performance measures. Ma and Nickerson (2006) propose that student questionaries for assessing the effectiveness of laboratory experiences should be based on a four broad categories as outlined by ABET (Feisel and Rosa 2005). These include Conceptual understanding, design skills, social skills and professional skills. Results of these surveys could then be used to form the radar charts as pictured below. Clear comparison could then be made, specifically between the learning outcomes of on-campus (local) and external (remote) apparatus users.

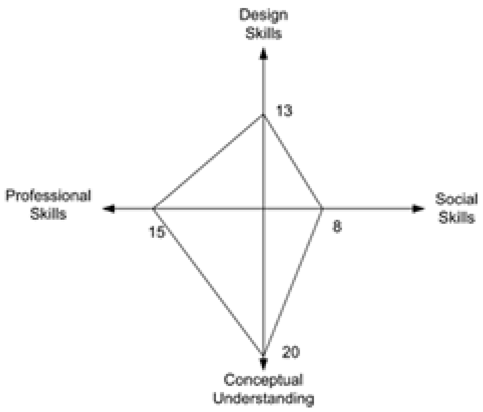


Figure E1 - Source: Ma and Nickerson (2006)

Ma and Nickerson (2006) provide the following table which summaries each of the four categories to be assessed by the proposed user perception survey.

Table E1 – Educational Goals of Laboratory Learning

Lab Goals	Description	Goals from ABET
Conceptual understanding	Extent to which laboratory activities help students understand and solve problems related to key concepts taught in the classroom.	Illustrate concepts and principles
Design skills	Extent to which laboratory activities increases student's ability to solve open-ended problems through the design and construction of new artifacts or processes.	Ability to design and investigate Understand the nature of science (scientific mind)
Social skills	Extent to which students learn how to productively perform engineering-related activities in groups.	Social skills and other productive team behaviors (communication, team interaction and problem solving, leadership)
Professional skills	Extent to which students become familiar with the technical skills they will be expected to have when practicing in the profession	Technical/procedural skills Introduce students to the world of scientists and engineers in practice Application of knowledge to practice

PROPOSED USER PERCEPTION SURVEY FOR ANALYSIS OF MEC2402 RAL APPARATUS EFFECTIVENESS (PAGE 2 of 2)

Inspection of the information in Table E1 has led to the development of the following survey questions which aim to assess the achievement of these objectives. It is important to note that these questions form only a proposed survey. Further investigation should be performed prior to development of final research tool.

1) Please indicate the manner in which you performed the investigations **(LOCAL / REMOTE)**

2) Prior to undertaking these investigations, indicate your understanding of the relevant concepts and principles (**1=poor , 10 =Excellent)**

3) Has use of the RAL improved your understanding of the relevant concepts? Indicate your level of understanding now that you have completed the laboratory **(1=poor , 10 =Excellent)**

4) Did you feel the use the remote access technology impaired your ability to investigate the concepts or understand the fundamental objectives of the experiment
(1=Strongly agree, 10 =Strongly disagree)

5) Rate the level of interaction you felt with the experiments/s **(1=poor , 10 =Excellent)**

6) Did you work in a group environment while complete these investigations **(YES/NO)**

  I. **If YES** – Was this interaction beneficial to the learning outcomes obtained **(1=Strongly disagree, 10 =Strongly agree)**

7) Did the results provide you with a link between course theory and practical applications? Indicate the strength of these links **(1=weak , 10 =strong)**

8) Overall did you find the use of this apparatus beneficial to your education? **(YES/NO)**

9) Briefly described any issues you had with the operation of the experiments

____

10) Briefly described aspects of the experiments you found helpful to your learning.

____

Appendix F

Project Schedule Details

Proposed Project Schedule

Primary milestones initially proposed for this project were as follows:

- **March 2013 –** Secure appropriate funding for manufacture of project.
- **May 2013 –** Complete initial research and literature review component.
- **July 2013 –** Complete design work
- **August 2013 –** Complete manufacture of apparatus
- **September 2013 –** Complete mechanical concept testing and evaluation
- **October 2013 –** Submit completed dissertation.

Achieved Project Schedule

Actual primary milestone achievements were as follows:

- **June 2013 –** Completed initial research and literature review component.
- **September 2013 –** Preliminary funding approval granted
- **September 2013 –** Completed manufacture of base frame
- **September 2013 –** Completed design work
- **October 2013 –** Completed mechanical concept testing and evaluation
- **October 2013 –** Submitted completed dissertation

Note: Final funding approval for this project was not granted at the time of thesis submission.

Appendix G

Project Risk Assessment – During Project

UNIVERSITY of SOUTHERN QUEENSLAND

Faculty of Engineering & Surveying

Hazard Checklist

Description of plant:	MEC2402 - Stress Analysis RAL apparatus
Activities (e.g. use, cleaning and maintenance):	Apparatus design, manufacture & assembly
Assessed by:	Scott Cox (project student)
Date:	28th June 2013

'Yes' to any of the following indicates the need to implement appropriate control measures

Entanglement	**YES**	**NO**
Can a person's hair, clothing, gloves, necktie, jewellery, cleaning brush or rag become entangled with moving parts of the plant?		X
Crushing	**YES**	**NO**
Can anyone be crushed due to:		
• material falling off the plant?		X
• uncontrolled or unexpected movement of the plant?		X
• lack of capacity for the plant to be slowed, stopped or immobilised?		X
• the plant tipping or rolling over?		X
• parts of the plant collapsing?		X
• coming into contact with moving parts of the plant during testing, inspection, operation, maintenance, cleaning or repair?		X
• being thrown off or under plant?		X
• being trapped between the plant and materials or fixed structures?		X
• other factors not mentioned?		X
Cutting, Stabbing or Puncturing	**YES**	**NO**
Can anyone be stabbed or punctured due to:		
• coming in contact with sharp or flying objects?	X	
• coming in contact with moving parts during testing, inspection, operation, maintenance, cleaning or repair?	X	
• the plant, parts of the plant or work pieces disintegrating?		X
• work pieces being ejected?		X
• the mobility of the plant?		X
• uncontrolled or unexpected movement of the plant?		X
• other factors not mentioned?		X
Shearing	**YES**	**NO**
Can anyone's body parts be sheared between two parts of the plant, or between a part of the plant and a work piece or structure?		X

Striking	YES	NO
Can anyone be struck by moving objects due to:		
• uncontrolled or unexpected movement of the plant or material handled by the plant?		X
• the plant, parts of the plant or work pieces disintegrating?		X
• work pieces being ejected?		X
• mobility of the plant?		X
• other factors not mentioned?		X
High Pressure Fluid	**YES**	**NO**
Can anyone come into contact with fluids under high pressure, due to plant failure or misuse of the plant?		X
Electrical	**YES**	**NO**
Can anyone be injured by electrical shock or burnt due to:		
• the plant contacting live electrical conductors?		X
• the plant working in close proximity to electrical conductors?		X
• overload of electrical circuits?		X
• damaged or poorly maintained electrical leads and cables?		X
• damaged electrical switches?		X
• water near electrical equipment?		X
• lack of isolation procedures?		X
• other factors not mentioned?		X
Explosion	**YES**	**NO**
Can anyone be injured by explosion of gases, vapours, liquids, dusts or other substances, triggered by the operation of the plant or by material handled by the plant?		X
Slipping, Tripping and Falling	**YES**	**NO**
Can anyone using the plant, or in the vicinity of the plant, slip, trip or fall due to:		
• uneven or slippery work surfaces?		X
• poor housekeeping, e.g. offcuts, cables, hoses obstructing walkways, spills not cleaned up?		X
• obstacles being placed in the vicinity of the plant?		X
• other factors not mentioned?		X
Can anyone fall from a height due to:		
• lack of a proper work platform?		X
• lack of proper stairs or ladders?		X
• lack of guardrails or other suitable edge protection?		X
• unprotected holes, penetrations or gaps?		X
• poor floor or walking surfaces, such as the lack of a slip-resistant surface?		X
• steep walking surfaces?		X
• collapse of the supporting structure?		X
• other factors not mentioned?		X
Ergonomic	**YES**	**NO**
Can anyone be injured due to:		
• poorly designed seating		X
• poorly designed operator controls?		X

• high forces?		X
• repetitive movements?		X
• awkward body posture or the need for excessive effort?	X	
• vibration?		X
• other factors not mentioned?		X
Combination of hazards	**YES**	**NO**
Can anyone be injured due to unexpected start-up, unexpected over-run/over-speed (or similar malfunction) from:		
• failure/disorder of the control system, for example, a hydraulic system?		X
• restoration of energy supply after an interruption?		X
• external influences on electrical equipment?		X
• other environmental factors (gravity, wind, etc.)?		X
• errors in the software?		X
• errors made by the operator ?		X
Other hazards	**YES**	**NO**
Can anyone be injured due to:		
• noise?	X	
• inadequate or poorly placed lighting?		X
• entry into any confined spaces of the plant?		X
• failure to select plant that is suitable for its intended use?		X
• contact with hot or cold parts of plant?		X
• exposure to hazardous chemicals, radiation or other emissions released by the plant?		X
• lack of operator competency?		X
• other factors not mentioned?		X

University of Southern Queensland
Risk Management Plan

Date: 28/05/13	**Faculty/Dept:** FoES	**Assessment completed by:** Scott Cox	**Contact No:**
What is the task? Design, manufacture & assembly of RAL apparatus		**Location where task is being conducted:** Off-Campus	
What is the operational significance of the task? Implementation of a laboratory equipment into a USQ engineering course		**What is the strategic significance of the task?** To improve educational outcomes for USQ student via exposure to physical results of Stress Analysis experiments.	
What are the nominal conditions?			
Personnel Project student - Scott Cox	Equipment MEC2402 RAL apparatus	Environment Off-Campus	Other
Briefly explain the procedure for this task (incl. Ref to other procedures) The task will first involve the completion of a design before selected manufacturing and assembly tasks to contribute towards completion of RAL apparatus. This excludes all electrical design and installation work.			

Risk Register and Analysis

Element or Sub Element/ Process Step	The Risk: What can happen and what will be the result	EXISTING CONTROLS	Risk Rating with existing controls? *See next page*			Is it ALARP? Yes/No	ADDITIONAL CONTROLS REQUIRED	Risk Rating with additional controls?			Is it ALARP? Yes/No	Risk Decision: Accept Transfer Treat
– List major steps or tasks in process	– Electric shock – Eye infection – Fire / explosion – Physical injury – Cut / graze – Chemical burn	List all current controls that are already in place or that will be used to undertake the task eg – List of Personal Protective Equipment (PPE) – Identify types facility, location – Existing safety measurers – Existing emergency procedures	Consequences	Likelihood	Rating		Additional controls may be required to reduce risk rating eg – Greater containment (PC2) – Additional PPE – gloves safety glasses – Specific induction / training	Consequences	Likelihood	Rating		
Misc. manufacture or assembly tasks	Cuts resulting from coming into contact with sharp objects.	N/A	2	C	M	NO	Use gloves at all times whilst handling plant or equipment	2	D	L	YES	ACCEPT
Misc. manufacture or assembly tasks	Manual handling issues resulting from lifting or transporting apparatus	N/A	2	C	M	NO	Use correct lifting techniques, team lifts or mechanical aids where required	2	D	L	YES	ACCEPT
Misc. manufacture or assembly tasks	Hearing damage from exposure to excessive noise	N/A	2	C	M	NO	Use hearing protection (ear plugs)	2	D	L	YES	ACCEPT
Misc. manufacture or assembly tasks	Eye injuries from flying debris	N/A	2	C	M	NO	Use safety glasses where required	2	D	L	YES	ACCEPT

USQ RISK RATING ADAPTED FROM AS436:2004

Note: In estimating the level of risk, initially estimate the risk with existing controls and then review risk controls if risk level arising from the risks is not minimal

TABLE 1 - CONSEQUENCE

Level	Descriptor	Examples of Description
1	Insignificant	No injuries. Minor delays. Little financial loss. $0 - $4,999*
2	Minor	First aid required. Small spill/gas release easily contained within work area. Nil environmental impact. Financial loss $5,000 - $49,999*
3	Moderate	Medical treatment required. Large spill/gas release contained on campus with help of emergency services. Nil environmental impact. Financial loss $50,000 - $99,999*
4	Major	Extensive or multiple injuries. Hospitalisation required. Permanent severe health effects. Spill/gas release spreads outside campus area. Minimal environmental impact. Financial loss $100,000 - $250,000*
5	Catastrophic	Death of one or more people. Toxic substance or toxic gas release spreads outside campus area. Release of genetically modified organism (s) (GMO). Major environmental impact. Financial loss greater than $250,000*

* Financial loss includes direct costs eg workers compensation and property damage and indirect costs, eg impact of loss of research data and accident investigation time.

TABLE 2 - PROBABILITY

Level	Descriptor	Examples of Description
A	Almost certain	The event is expected to occur in most circumstances. Common or repetitive occurrence at USQ. Constant exposure to hazard. Very high probability of damage.
B	Likely	The event will probably occur in most circumstances. Known history of occurrence at USQ. Frequent exposure to hazard. High probability of damage.
C	Possible	The event could occur at some time. History of single occurrence at USQ. Regular or occasional exposure to hazard. Moderate probability of damage.
D	Unlikely	The event is not likely to occur. Known occurrence in industry. Infrequent exposure to hazard. Low probability of damage.
E	Rare	The event may occur only in exceptional circumstances. No reported occurrence globally. Rare exposure to hazard. Very low probability of damage. Requires multiple system failures.

USQ RISK RATING ADAPTED FROM AS436:2004

TABLE 3 – RISK RATING

Probability	Consequence				
	Insignificant 1	Minor 2	Moderate 3	Major 4	Catastrophic 5
A (Almost certain)	M	H	E	E	E
B (Likely)	M	H	H	E	E
C (Possible)	L	M	H	H	H
D (Unlikely)	L	L	M	M	M
E (Rare)	L	L	L	L	L

Recommended Action Guide:

Abbrev	Action Level	Descriptor
E	Extreme	The proposed task or process activity MUST NOT proceed until the supervisor has reviewed the task or process design and risk controls. They must take steps to firstly eliminate the risk and if this is not possible to introduce measures to control the risk by reducing the level of risk to the lowest level achievable. In the case of an existing hazard that is identified, controls must be put in place immediately.
H	High	Urgent action is required to eliminate or reduce the foreseeable risk arising from the task or process. The supervisor must be made aware of the hazard. However, the supervisor may give special permission for staff to undertake some high risk activities provided that system of work is clearly documented, specific training has been given in the required procedure and an adequate review of the task and risk controls has been undertaken. This includes providing risk controls identified in Legislation, Australian Standards, Codes of Practice etc.* A detailed Standard Operating Procedure is required. * and monitoring of its implementation must occur to check the risk level
M	Moderate	Action to eliminate or reduce the risk is required within a specified period. The supervisor should approve all moderate risk task or process activities. A Standard Operating Procedure or Safe Work Method statement is required
L	Low	Manage by routine procedures.

*Note: These regulatory documents identify specific requirements/controls that must be implemented to reduce the risk of an individual undertaking the task to a level that the regulatory body identifies as being acceptable.

Appendix H

Project Risk Assessment – Beyond Project Completion

UNIVERSITY of SOUTHERN QUEENSLAND

Faculty of Engineering & Surveying

Hazard Checklist

Description of plant:	MEC2402 - Stress Analysis RAL apparatus
Activities (e.g. use, cleaning and maintenance):	Apparatus operation and maintenance
Assessed by:	Scott Cox (project student)
Date:	28th June 2013

'Yes' to any of the following indicates the need to implement appropriate control measures

Entanglement	**YES**	**NO**
Can a person's hair, clothing, gloves, necktie, jewellery, cleaning brush or rag become entangled with moving parts of the plant?	X	
Crushing	**YES**	**NO**
Can anyone be crushed due to:		
• material falling off the plant?		X
• uncontrolled or unexpected movement of the plant?	X	
• lack of capacity for the plant to be slowed, stopped or immobilised?	X	
• the plant tipping or rolling over?	X	
• parts of the plant collapsing?		X
• coming into contact with moving parts of the plant during testing, inspection, operation, maintenance, cleaning or repair?	X	
• being thrown off or under plant?		X
• being trapped between the plant and materials or fixed structures?		X
• other factors not mentioned?		X
Cutting, Stabbing or Puncturing	**YES**	**NO**
Can anyone be stabbed or punctured due to:		
• coming in contact with sharp or flying objects?		X
• coming in contact with moving parts during testing, inspection, operation, maintenance, cleaning or repair?	X	
• the plant, parts of the plant or work pieces disintegrating?		X
• work pieces being ejected?		X
• the mobility of the plant?		X
• uncontrolled or unexpected movement of the plant?	X	
• other factors not mentioned?		X
Shearing	**YES**	**NO**
Can anyone's body parts be sheared between two parts of the plant, or between a part of the plant and a work piece or structure?	X	

Striking	YES	NO
Can anyone be struck by moving objects due to:		
• uncontrolled or unexpected movement of the plant or material handled by the plant?	X	
• the plant, parts of the plant or work pieces disintegrating?		X
• work pieces being ejected?		X
• mobility of the plant?		X
• other factors not mentioned?		X
High Pressure Fluid	**YES**	**NO**
Can anyone come into contact with fluids under high pressure, due to plant failure or misuse of the plant?		X
Electrical	**YES**	**NO**
Can anyone be injured by electrical shock or burnt due to:		
• the plant contacting live electrical conductors?		X
• the plant working in close proximity to electrical conductors?		X
• overload of electrical circuits?		X
• damaged or poorly maintained electrical leads and cables?	X	
• damaged electrical switches?		X
• water near electrical equipment?	X	
• lack of isolation procedures?	X	
• other factors not mentioned?		X
Explosion	**YES**	**NO**
Can anyone be injured by explosion of gases, vapours, liquids, dusts or other substances, triggered by the operation of the plant or by material handled by the plant?		X
Slipping, Tripping and Falling	**YES**	**NO**
Can anyone using the plant, or in the vicinity of the plant, slip, trip or fall due to:		
• uneven or slippery work surfaces?		X
• poor housekeeping, e.g. offcuts, cables, hoses obstructing walkways, spills not cleaned up?	X	
• obstacles being placed in the vicinity of the plant?		X
• other factors not mentioned?		X
Can anyone fall from a height due to:		
• lack of a proper work platform?		X
• lack of proper stairs or ladders?		X
• lack of guardrails or other suitable edge protection?		X
• unprotected holes, penetrations or gaps?		X
• poor floor or walking surfaces, such as the lack of a slip-resistant surface?		X
• steep walking surfaces?		X
• collapse of the supporting structure?		X
• other factors not mentioned?		X
Ergonomic	**YES**	**NO**
Can anyone be injured due to:		
• poorly designed seating		X
• poorly designed operator controls?		X

• high forces?		X
• repetitive movements?		X
• awkward body posture or the need for excessive effort?	X	
• vibration?		X
• other factors not mentioned?		X
Combination of hazards	**YES**	**NO**
Can anyone be injured due to unexpected start-up, unexpected over-run/over-speed (or similar malfunction) from:		
• failure/disorder of the control system, for example, a hydraulic system?		X
• restoration of energy supply after an interruption?		X
• external influences on electrical equipment?		X
• other environmental factors (gravity, wind, etc.)?		X
• errors in the software?		X
• errors made by the operator ?		X
Other hazards	**YES**	**NO**
Can anyone be injured due to:		
• noise?		X
• inadequate or poorly placed lighting?		X
• entry into any confined spaces of the plant?		X
• failure to select plant that is suitable for its intended use?		X
• contact with hot or cold parts of plant?		X
• exposure to hazardous chemicals, radiation or other emissions released by the plant?		X
• lack of operator competency?	X	
• other factors not mentioned?		X

University of Southern Queensland
Risk Management Plan

Date: 28/05/13	**Faculty/Dept:** FoES	**Assessment completed by:** Scott Cox	**Contact No:**
What is the task? Implement a remote-access apparatus into the course MEC2402 – Stress Analysis.		**Location where task is being conducted:** USQ Toowoomba Campus	
What is the operational significance of the task? To enable staff and students to physically interact with a newly developed laboratory apparatus.		**What is the strategic significance of the task?** To improve educational outcomes for USQ student via exposure to physical results of Stress Analysis experiments.	
What are the nominal conditions?			
Personnel USQ students, academic and technical staff	Equipment MEC2402 RAL apparatus	Environment Entire University Campus	Other
Briefly explain the procedure for this task (incl. Ref to other procedures) The task will involve transporting and operation of a remote-access laboratory experiment at locations around the USQ campus			

J:\usqsafe\400 - Risk Management\410 General\GENERIC Risk Management Plan V1.0.doc

Risk Register and Analysis

Element or Sub Element/ Process Step	The Risk: What can happen and what will be the result	EXISTING CONTROLS	Risk Rating with existing controls? *See next page*			Is it ALARP? Yes/No	ADDITIONAL CONTROLS REQUIRED	Risk Rating with additional controls?			Is it ALARP? Yes/No	Risk Decision: Accept Transfer Treat
– List major steps or tasks in process	– Electric shock – Eye infection – Fire / explosion – Physical injury – Cut / graze – Chemical burn	List all current controls that are already in place or that will be used to undertake the task eg – List of Personal Protective Equipment (PPE) – Identify types facility, location – Existing safety measurers – Existing emergency procedures	Consequences	Likelihood	Rating		Additional controls may be required to reduce risk rating eg – Greater containment (PC2) – Additional PPE – gloves safety glasses – Specific induction /training	Consequences	Likelihood	Rating		
Transportation of apparatus around USQ campus	- Uncontrolled movement of apparatus - Apparatus tipping or rolling over -lack of capacity for apparatus to be stopped or controlled	N/A	3	C	H	NO	- Design frame to include appropriate handle to control and move apparatus. - Selection of castors 'fixed' at the front of frame and 'swivel with brake' at the rear end. - Design frame with an appropriate base of support and a centre of gravity as low as reasonably practical	3	D	M	YES	ACCEPT
Transportation of apparatus around USQ campus	- Damage to electrical cables	N/A	1	C	L	NO	- Install appropriate storage mechanism for electrical cables whilst in motion - Positioning of cables at rear of frame (whilst in motion)	1	D	L	YES	ACCEPT
Transportation of apparatus around USQ campus	- Water near electrical equipment	Cabinet + Perspex cover	4	D	M	NO	Installation of stickers warning against transportation or operation of apparatus in poor weather.	4	E	L	YES	ACCEPT
Experimental use by students	- Contact with moving parts	Perspex cover	3	C	H	NO	Interlock guarding system to ensure accidental operation of equipment cannot occur once cover is removed	3	E	L	YES	ACCEPT
Experimental use by students	- Contact with electrical components - Tripping on cables	N/A	4	C	H	NO	-Mechanical lock on doors to prevent unauthorised personnel from opening electrical cabinet. - Use of highly visible colour for cables	4	E	L	YES	ACCEPT
Maintenance	- Contact with moving parts - Contact with live electrical components	Interlocks on cover	4	D	M	NO	Installation of appropriate warning stickers	4	E		YES	ACCEPT

USQ RISK RATING ADAPTED FROM AS436:2004

Note: In estimating the level of risk, initially estimate the risk with existing controls and then review risk controls if risk level arising from the risks is not minimal

TABLE 1 - CONSEQUENCE

Level	Descriptor	Examples of Description
1	Insignificant	No injuries. Minor delays. Little financial loss. $0 - $4,999*
2	Minor	First aid required. Small spill/gas release easily contained within work area. Nil environmental impact. Financial loss $5,000 - $49,999*
3	Moderate	Medical treatment required. Large spill/gas release contained on campus with help of emergency services. Nil environmental impact. Financial loss $50,000 - $99,999*
4	Major	Extensive or multiple injuries. Hospitalisation required. Permanent severe health effects. Spill/gas release spreads outside campus area. Minimal environmental impact. Financial loss $100,000 - $250,000*
5	Catastrophic	Death of one or more people. Toxic substance or toxic gas release spreads outside campus area. Release of genetically modified organism (s)(GMO). Major environmental impact. Financial loss greater than $250,000*

* Financial loss includes direct costs eg workers compensation and property damage and indirect costs, eg impact of loss of research data and accident investigation time.

TABLE 2 - PROBABILITY

Level	Descriptor	Examples of Description
A	Almost certain	The event is expected to occur in most circumstances. Common or repetitive occurrence at USQ. Constant exposure to hazard. Very high probability of damage.
B	Likely	The event will probably occur in most circumstances. Known history of occurrence at USQ. Frequent exposure to hazard. High probability of damage.
C	Possible	The event could occur at some time. History of single occurrence at USQ. Regular or occasional exposure to hazard. Moderate probability of damage.
D	Unlikely	The event is not likely to occur. Known occurrence in industry. Infrequent exposure to hazard. Low probability of damage.
E	Rare	The event may occur only in exceptional circumstances. No reported occurrence globally. Rare exposure to hazard. Very low probability of damage. Requires multiple system failures.

USQ RISK RATING ADAPTED FROM AS436:2004

TABLE 3 – RISK RATING

Probability	Consequence				
	Insignificant 1	Minor 2	Moderate 3	Major 4	Catastrophic 5
A (Almost certain)	M	H	E	E	E
B (Likely)	M	H	H	E	E
C (Possible)	L	M	H	H	H
D (Unlikely)	L	L	M	M	M
E (Rare)	L	L	L	L	L

Recommended Action Guide:

Abbrev	Action Level	Descriptor
E	Extreme	The proposed task or process activity MUST NOT proceed until the supervisor has reviewed the task or process design and risk controls. They must take steps to firstly eliminate the risk and if this is not possible to introduce measures to control the risk by reducing the level of risk to the lowest level achievable. In the case of an existing hazard that is identified, controls must be put in place immediately.
H	High	Urgent action is required to eliminate or reduce the foreseeable risk arising from the task or process. The supervisor must be made aware of the hazard. However, the supervisor may give special permission for staff to undertake some high risk activities provided that system of work is clearly documented, specific training has been given in the required procedure and an adequate review of the task and risk controls has been undertaken. This includes providing risk controls identified in Legislation, Australian Standards, Codes of Practice etc.* A detailed Standard Operating Procedure is required. * and monitoring of its implementation must occur to check the risk level
M	Moderate	Action to eliminate or reduce the risk is required within a specified period. The supervisor should approve all moderate risk task or process activities. A Standard Operating Procedure or Safe Work Method statement is required
L	Low	Manage by routine procedures.

*Note: These regulatory documents identify specific requirements/controls that must be implemented to reduce the risk of an individual undertaking the task to a level that the regulatory body identifies as being acceptable.

Appendix I

Technical Data & Drawings

GREY TP RUBBER CASTORS - FIXED, SWIVEL & TOTAL LOCK BRAKE

- Swivel castors with brake feature directional lock as standard
- Excellent for most surfaces
- Durable, non marking grey TP (Thermo Plastic) rubber

SWIVEL TYPE CASTOR: GREY TP RUBBER

Part Number	Wheel Diameter mm	Wheel Width mm	Castor Height mm	Plate Type	Capacity kg	Style	JBS No
06832018	80	32	110	Config A 80mm x 100mm	60	Swivel	JBS-CAST-3-GR-RBR-S
06832035	100	34	130	Config A 80mm x 100mm	80	Swivel	JBS-CAST-4-GR-RBR-S
06832120	125	37	152	Config A 80mm x 100mm	105	Swivel	JBS-CAST-5-GR-RBR-S
06832103	150	40	192	Config B 110mm x 140mm	145	Swivel	JBS-CAST-6-GR-RBR-S

FIXED TYPE CASTOR: GREY TP RUBBER

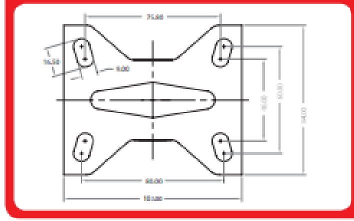
Part Number	Wheel Diameter mm	Wheel Width mm	Castor Height mm	Plate Type	Capacity kg	Style	JBS No
06832052	80	32	110	Config A 80mm x 100mm	60	Fixed	JBS-CAST-3-GR-RBR-F
06832069	100	34	130	Config C 84mm x 102mm	80	Fixed	JBS-CAST-4-GR-RBR-F
06832256	125	37	152	Config C 84mm x 102mm	105	Fixed	JBS-CAST-5-GR-RBR-F
06832273	150	40	192	Config C 84mm x 102mm	145	Fixed	JBS-CAST-6-GR-RBR-F

SWIVEL TYPE CASTOR WITH BRAKE: GREY TP RUBBER

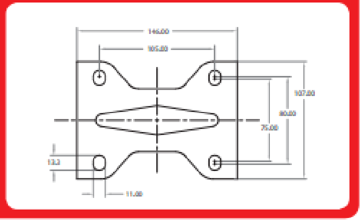
Part Number	Wheel Diameter mm	Wheel Width mm	Castor Height mm	Plate Type	Capacity kg	Style	JBS No
06832171	80	32	110	Config A 80mm x 100mm	60	Swivel/ Brake	JBS-CAST-3-GR-RBR-S-B
06832137	100	34	130	Config A 80mm x 100mm	80	Swivel/ Brake	JBS-CAST-4-GR-RBR-S-B
06832290	125	37	152	Config B 110mm x 140mm	105	Swivel/ Brake	JBS-CAST-5-GR-RBR-S-B
06832307	150	40	192	Config B 110mm x 140mm	145	Swivel/ Brake	JBS-CAST-6-GR-RBR-S-B

BASE PLATE TYPE

Config C (84mm x 102mm)



Config D (107mm x 146mm)



POLYURETHANE CASTORS - FIXED, SWIVEL & TOTAL LOCK BRAKE

- Long lasting and non-marking
- Excellent for most surfaces
- Can take higher loads than similar wheels
- Can take higher loads than similar wheels
- Long lasting and non-marking

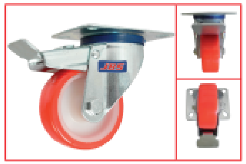
SWIVEL TYPE CASTOR: RED POLYURETHANE

Part Number	Wheel Diameter mm	Wheel Width mm	Castor Height mm	Plate Type	Capacity kg	Style	JBS No
06832086	80	30	110	Config A 80mm x 100mm	100	Swivel	JBS-CAST-3-POLY-S
06832239	100	30	130	Config A 80mm x 100mm	120	Swivel	JBS-CAST-4-POLY-S

FIXED TYPE CASTOR: RED POLYURETHANE

Part Number	Wheel Diameter mm	Wheel Width mm	Castor Height mm	Plate Type	Capacity kg	Style	JBS No
06832222	80	30	110	Config C 84mm x 102mm	100	Fixed	JBS-CAST-3-POLY-F
06832205	100	30	130	Config C 84mm x 102mm	120	Fixed	JBS-CAST-4-POLY-F

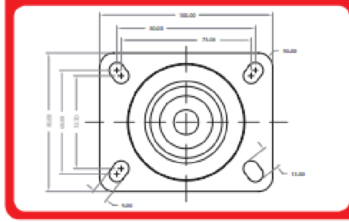
SWIVEL TYPE CASTOR WITH BRAKE: RED POLYURETHANE



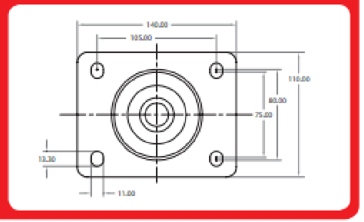
Part Number	Wheel Diameter mm	Wheel Width mm	Castor Height mm	Plate Type	Capacity kg	Style	JBS No
06832154	80	30	110	Config A 80mm x 100mm	100	Swivel/ Brake	JBS-CAST-3-POLY-S-B
06832188	100	30	130	Config A 80mm x 100mm	120	Swivel/ Brake	JBS-CAST-4-POLY-S-B

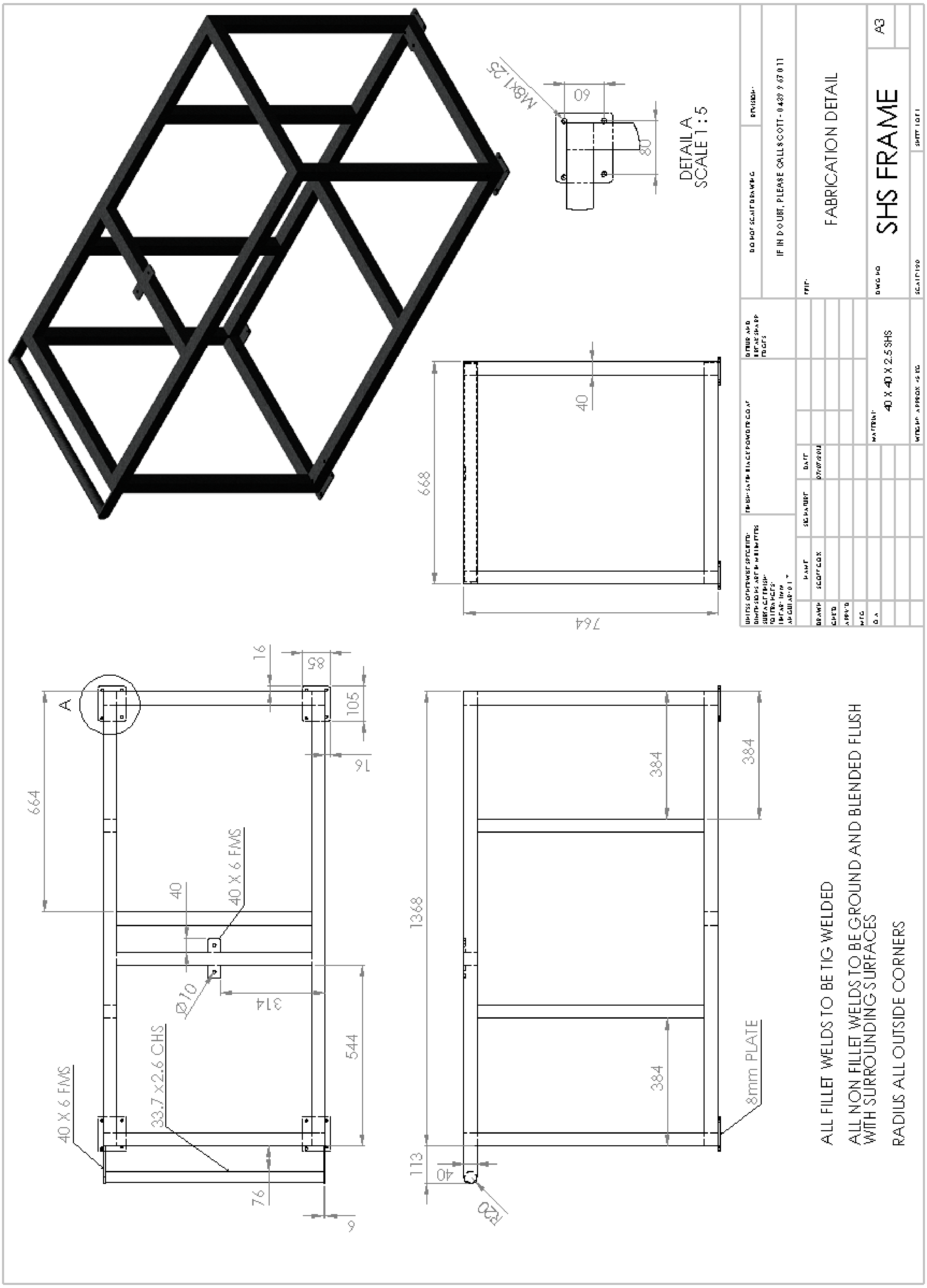
BASE PLATE TYPE

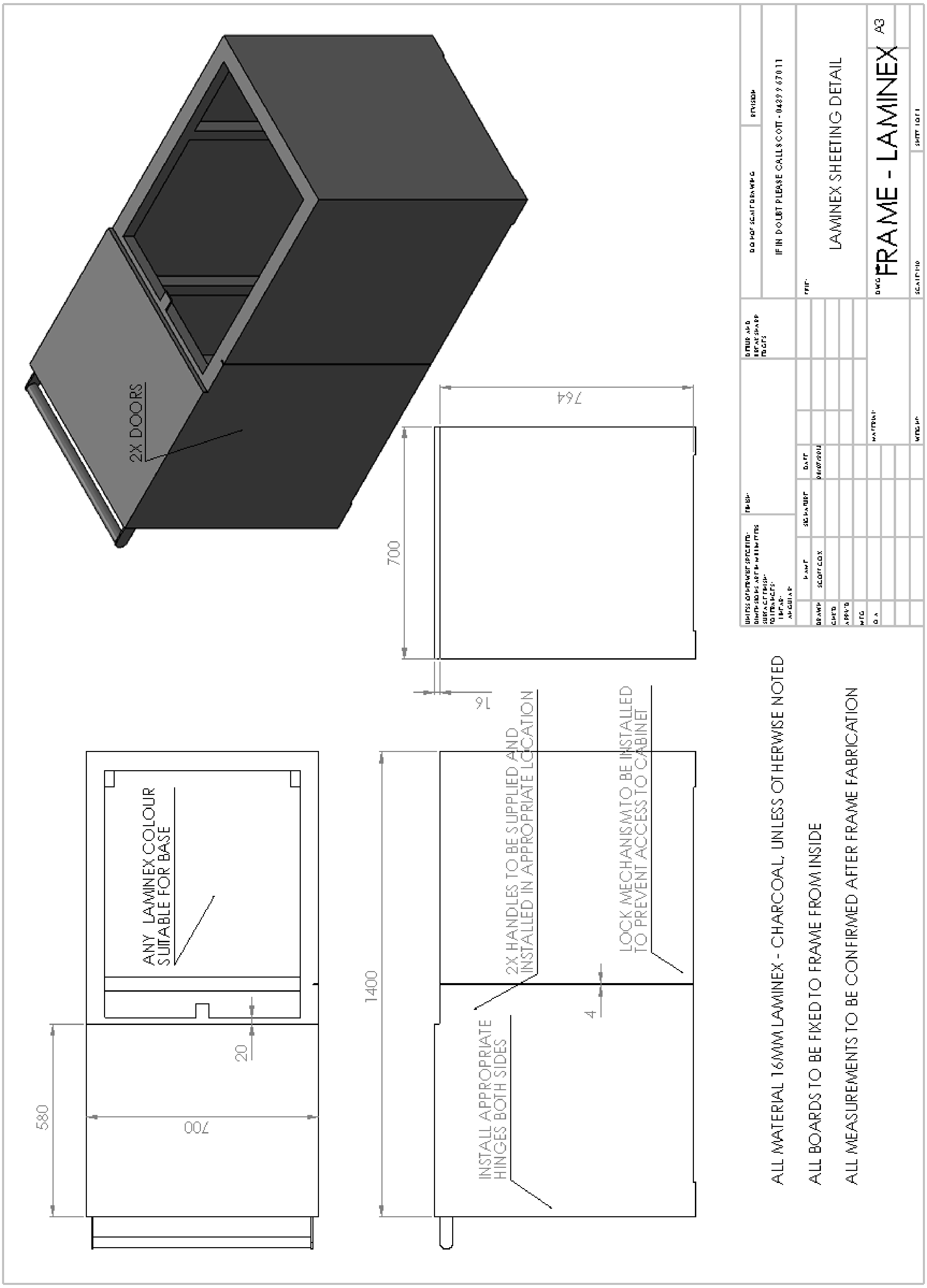
Config A (80mm x 100mm)



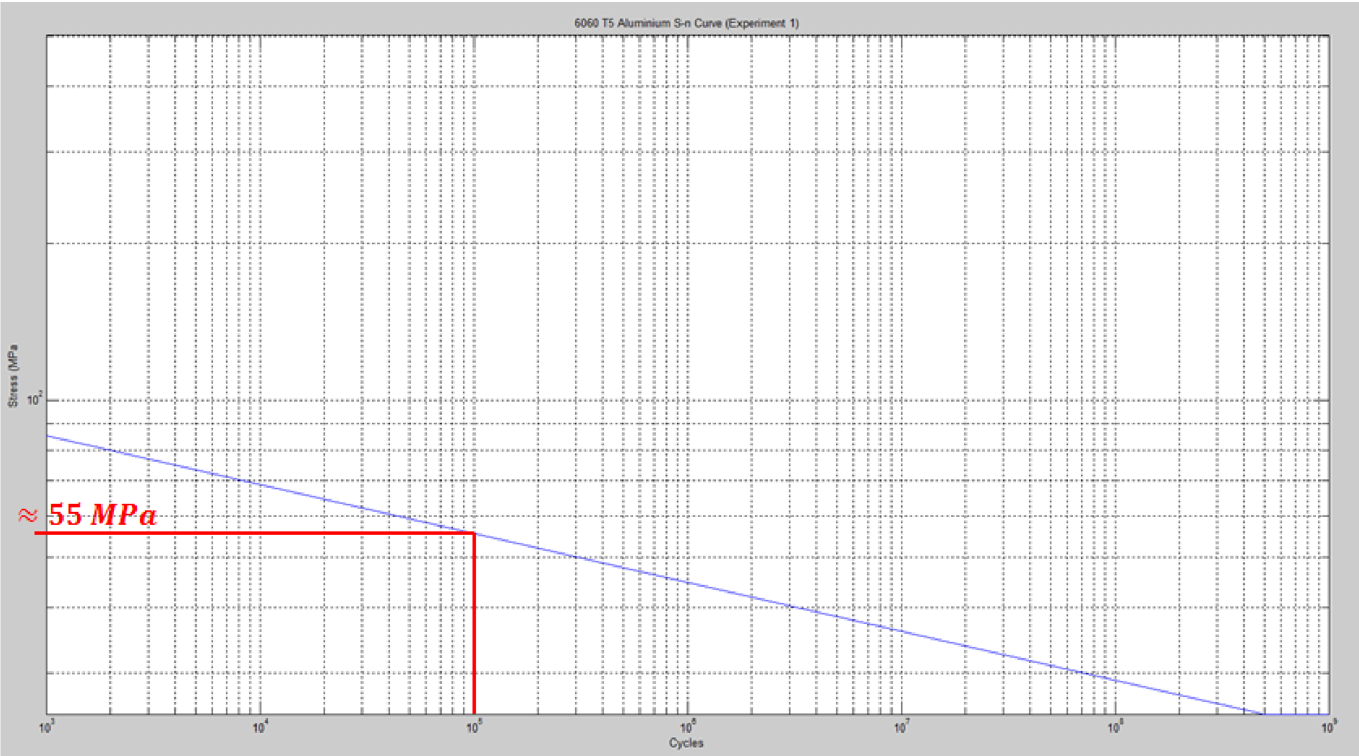
Config B (110mm x 140mm)



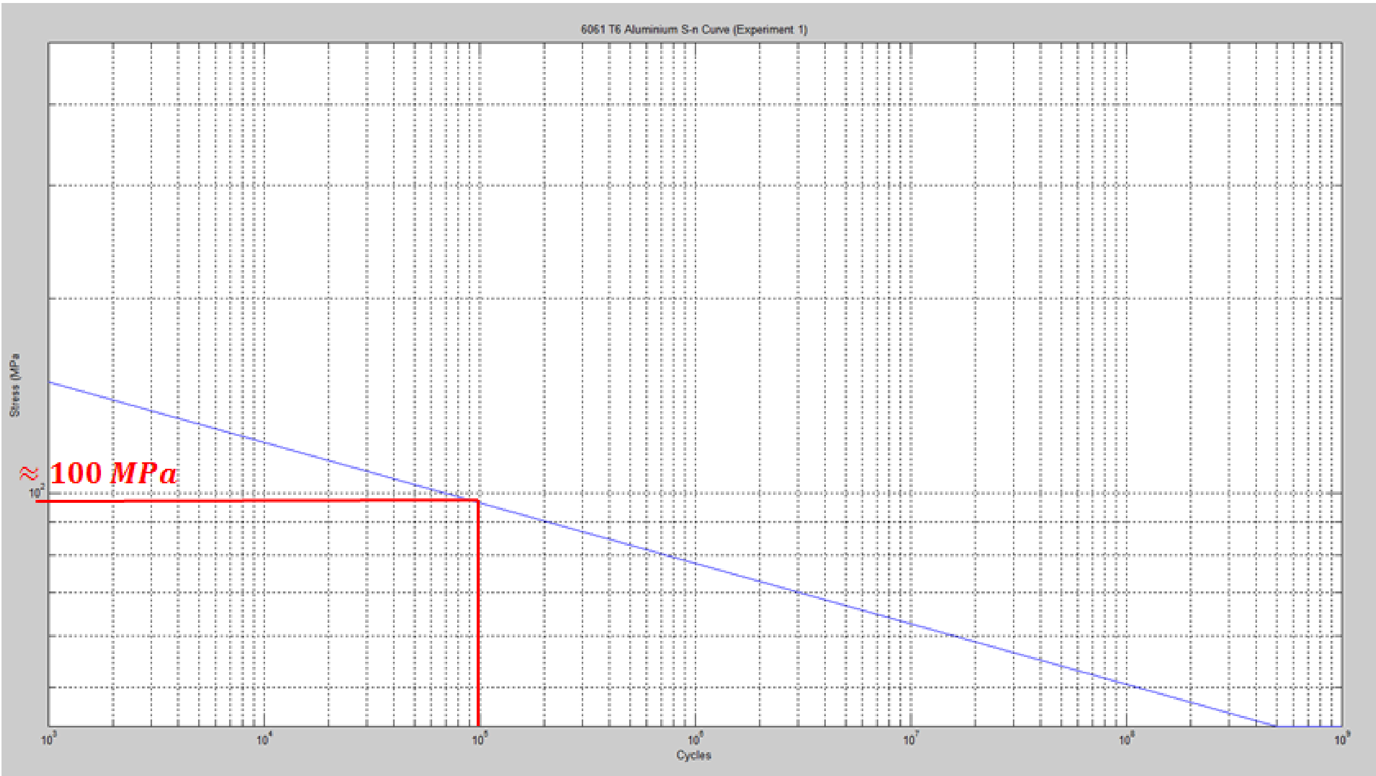

SHS FRAME
FABRICATION DETAIL
40 X 40 X 2.5 SHS
A3
DETAIL A
SCALE 1 : 5
M8x1.25
ALL FILLET WELDS TO BE TIG WELDED
ALL NON FILLET WELDS TO BE GROUND AND BLENDED FLUSH WITH SURROUNDING SURFACES
RADIUS ALL OUTSIDE CORNERS
40 X 6 F/MS
33.7 x 2.6 CHS
8mm PLATE
Ø10
R20
A


2X DOORS
764
700
16
1400
4
580
700
20
ANY LAMINEX COLOUR SUITABLE FOR BASE
2X HANDLES TO BE SUPPLIED AND INSTALLED IN APPROPRIATE LOCATION
LOCK MECHANISM TO BE INSTALLED TO PREVENT ACCESS TO CABINET
INSTALL APPROPRIATE HINGES BOTH SIDES
ALL MATERIAL 16MM LAMINEX - CHARCOAL, UNLESS OTHERWISE NOTED
ALL BOARDS TO BE FIXED TO FRAME FROM INSIDE
ALL MEASUREMENTS TO BE CONFIRMED AFTER FRAME FABRICATION
SCOTT COX
IF IN DOUBT PLEASE CALL SCOTT - 0439 967011
LAMINEX SHEETING DETAIL
FRAME - LAMINEX
A3

EXPERIMENT 1 – 6060 T5 ALUMINIUM



EXPERIMENT 1 – 6061 T6 ALUMINIUM



LINEAR ACTUATOR LA23

Description Data sheet 2D/3D Resources & downloads

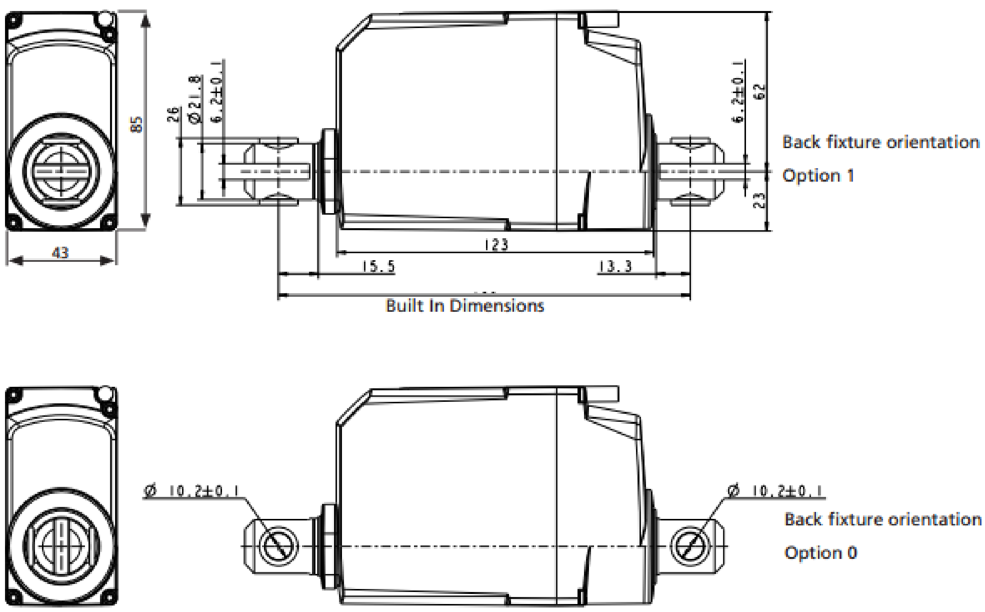
The LA23 actuator is a small and strong push or pull actuator (up to 2500 N).
The LA23 can be used in various applications where size is important.

Some of the benefits the LA23 offers you are:

- Compact design
- High lifting force
- Exchangeable cables
- Available with intelligent control (IC) (LA23 TECHLINE only)

- Max. Thrust: 2500 N
- Max. Speed: 12,6 mm/s

Dimensions:



Tolerances:
For built-in dimensions and stroke ± 2 mm.

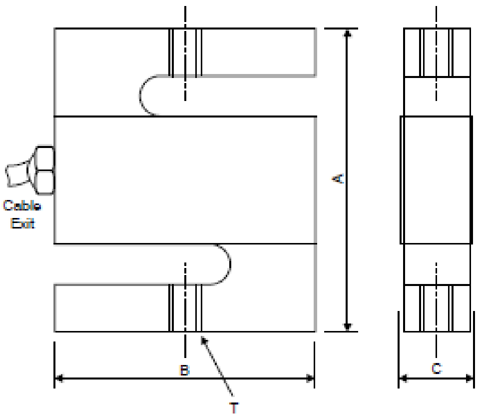
Model PT4000

UNIVERSAL S-BEAM LOAD CELL

Specifications

Note: All specifications are a maximum, as a % (±) of full load, unless otherwise stated.

Nominal Capacity	50lb ~ 20klb 20kg ~ 5t
Signal Output at Capacity	3mV/V ± 0.1%
Linearity Error	< 0.017% FSO
Non-Repeatability	< 0.010% FSO
Combined Error	< 0.023% FSO
Hysteresis	< 0.020% FSO
Creep/Zero Return (30 mins)	< 0.023% / 0.017% FSO
Zero Balance	< 1.000% Capacity
Temperature Effect on Span/10°C	< 0.010% FSO
Temperature Effect on Zero/10°C	< 0.015% Capacity
Compensated Temperature Range	14 ~ 104°F / -10 ~ 40°C
Operating Temperature Range	0 ~ 150°F / -18 ~ 65°C
Service Load	100% of Rated Capacity
Safe Load	150% of Rated Capacity
Safe Sideload	100% of Rated Capacity
Ultimate Load	300% of Rated Capacity
Input Resistance	415Ω ± 15Ω
Output Resistance	352Ω ± 3Ω
Insulation Resistance	> 5000 MΩ at 100V DC
Excitation Voltage (Recommended)	5 ~ 15V AC/DC
Excitation Voltage (Maximum)	18V AC/DC
Storage Temperature Range	-60 ~ 185°F / -50 ~ 85°C
Cable Type	4.5mm, Screened, PUR Sheath 4 Core x 0.24mm² (24 AWG)
Cable Length	20 Feet / 6 Metres
Material	Alloy Tool Steel
Finish	Electroless Nickel Plated



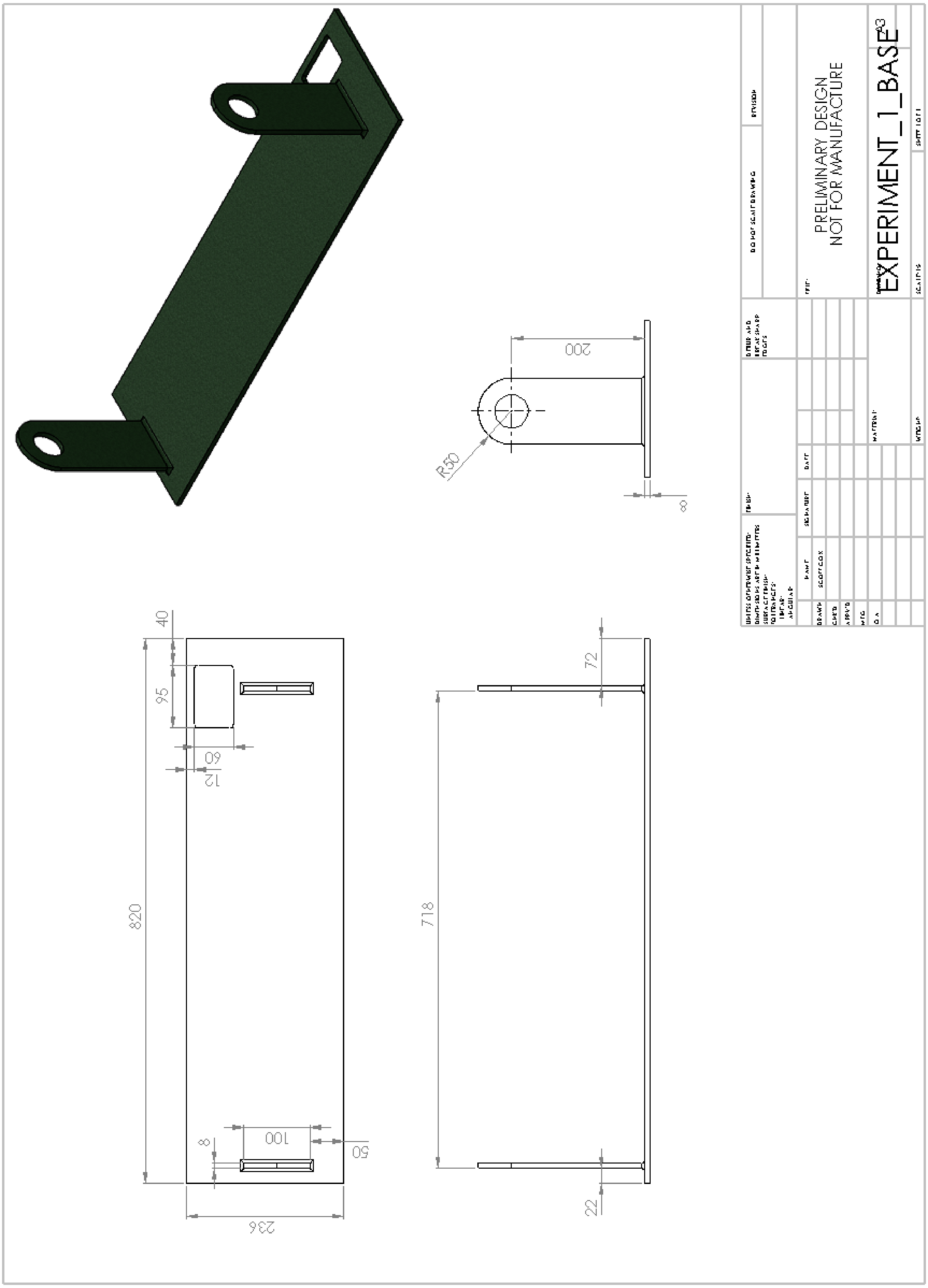
Load Cell Dimensions

	A	B	C	T	Weight
50lb ~ 300lb	2.5	2	0.62	¼ UNF	0.90
500lb ~ 1.5klb	2.5	2	0.87	½ UNF	1.10
2klb ~ 2.5klb	2.5	2	1.1	½ UNF	1.40
3klb	3	2	1.1	½ UNF	1.60
5klb ~ 10klb	4	3	1.3	¾ UNF	3.30
20klb	5.9	4.5	2	1¼ UNF	5.75

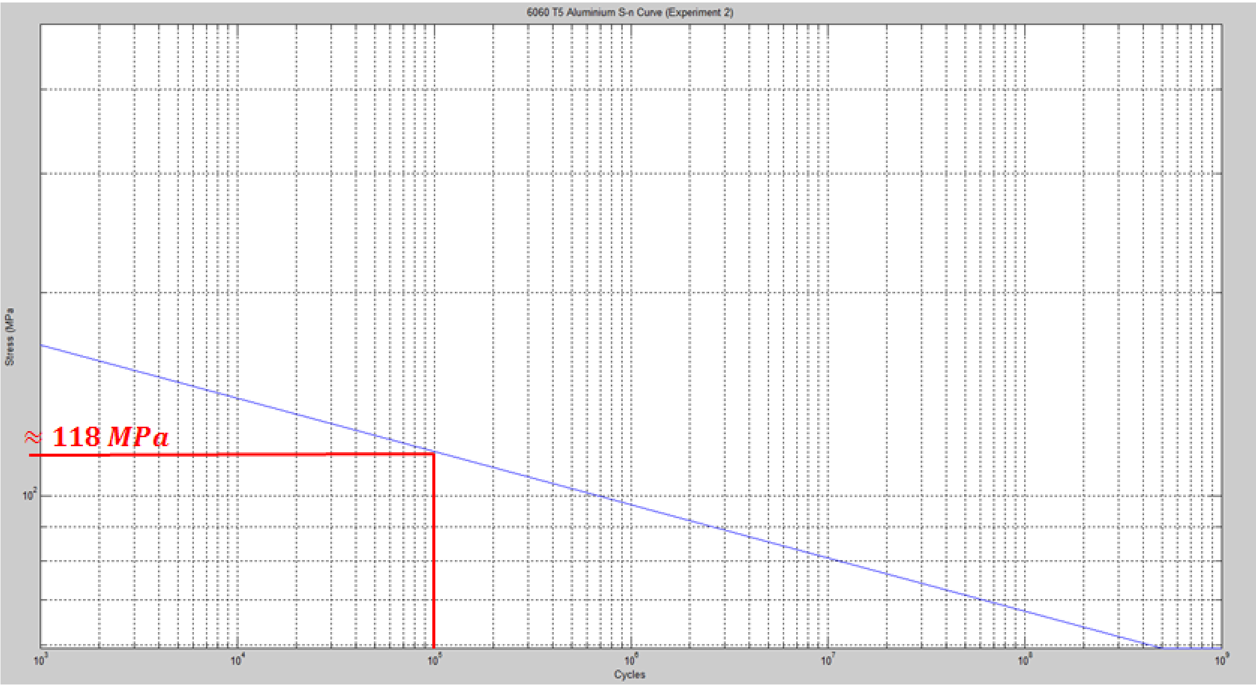
Dimensions in inches   Weight in lb

	A	B	C	T	Weight
20kg ~ 100kg	63.5	51	16	M8 x 1.25P	0.41
200kg ~ 500kg	63.5	51	22	M12 x 1.75P	0.52
1t	63.5	51	28	M12 x 1.75P	0.64
2t	101.6	76	33	M20 x 1.5P	1.50
3t ~ 5t	101.6	76	33	M24 x 2P	1.50

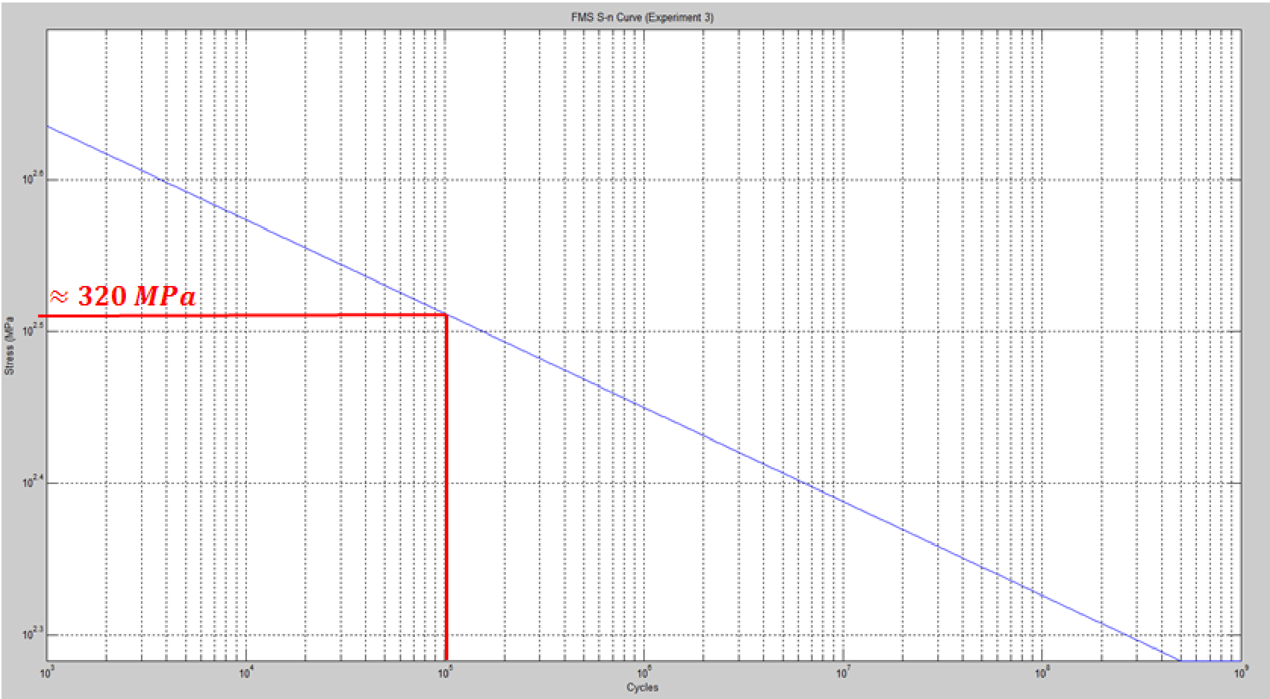
Dimensions in mm   Weight in kg

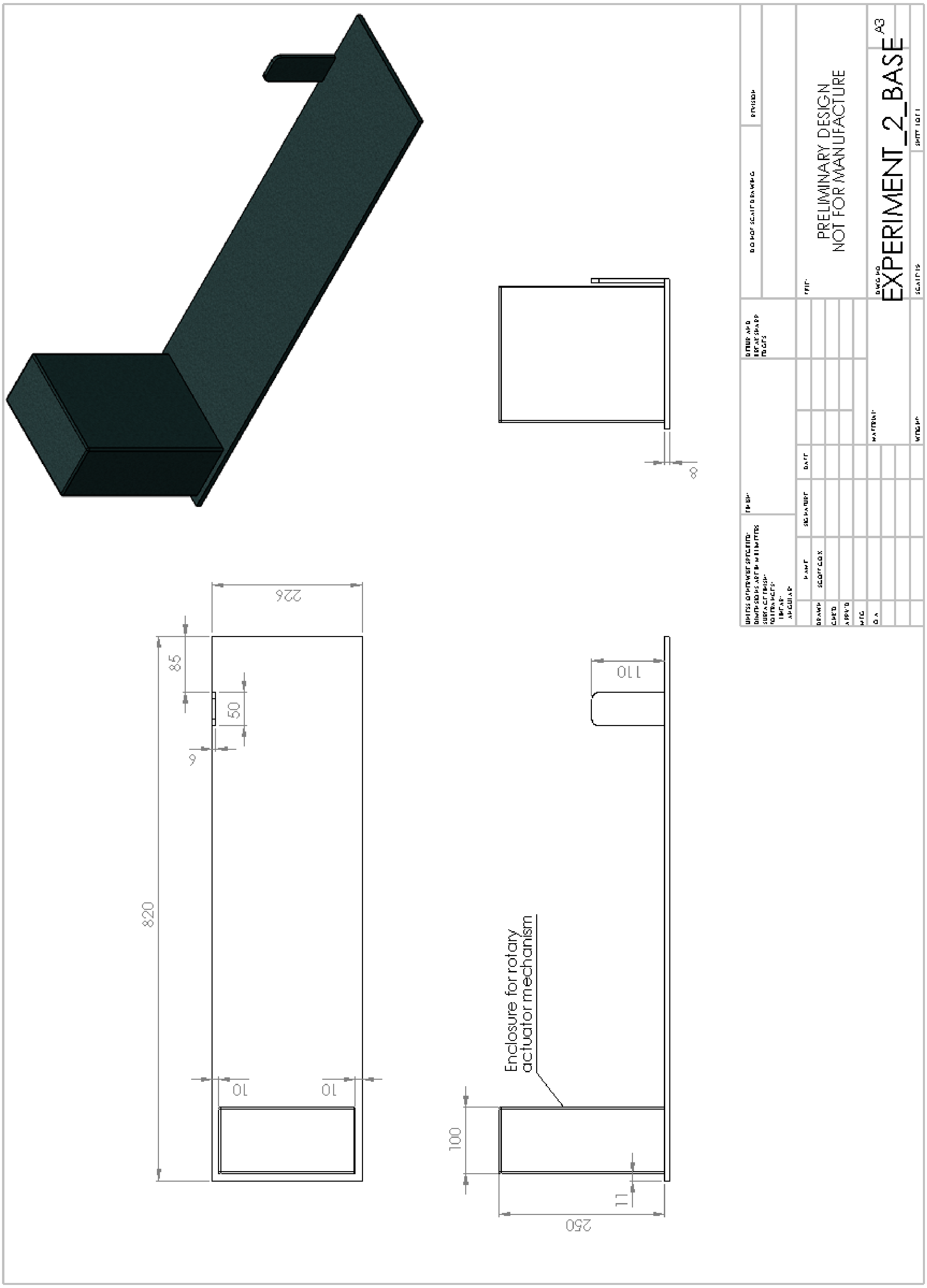

PRELIMINARY DESIGN
NOT FOR MANUFACTURE
EXPERIMENT_1_BASE
A3
DO NOT SCALE DRAWING
REVISION
SCOTT COX
R50
200
8
820
40
95
60
12
100
8
50
236
718
72
22

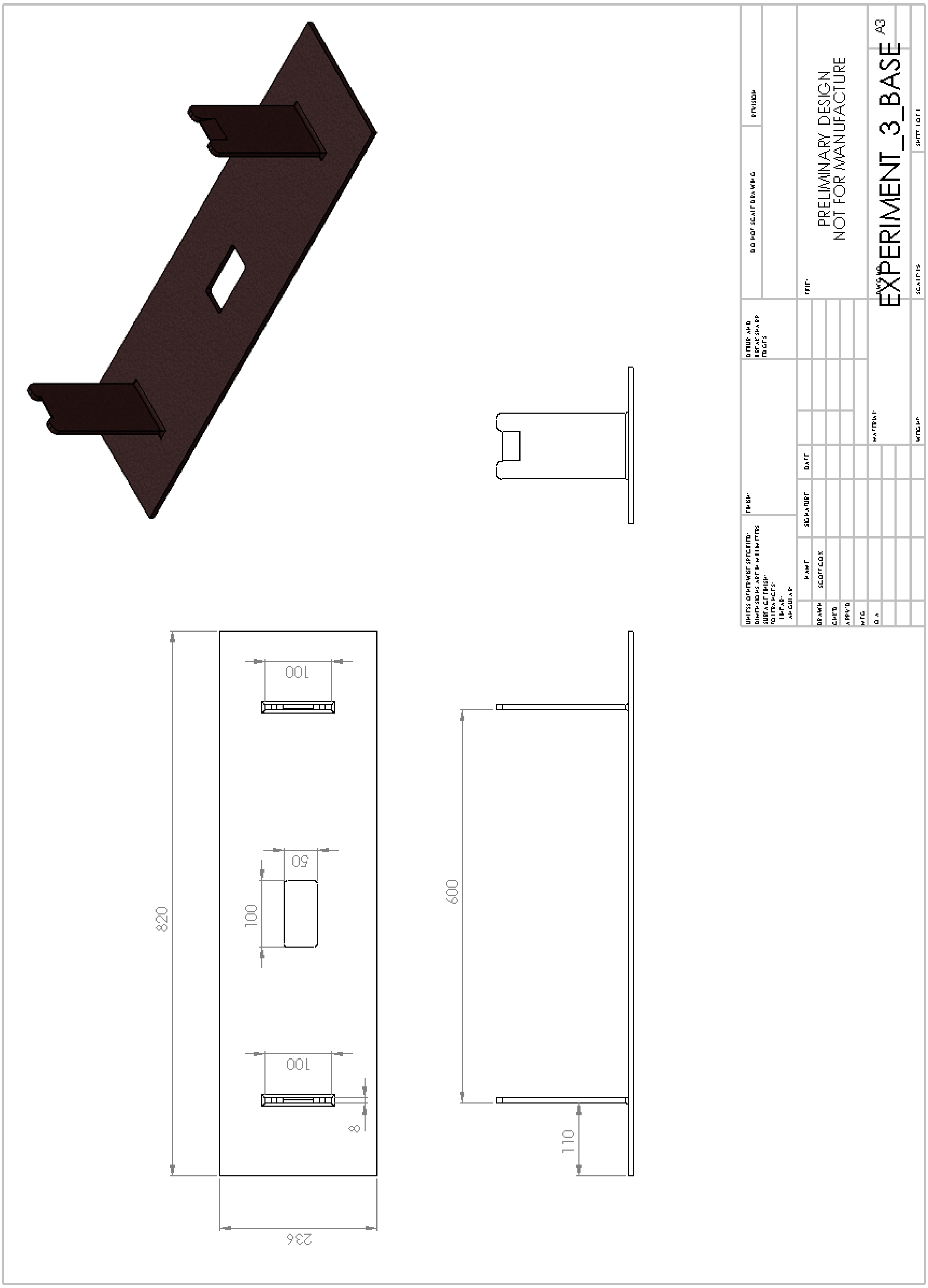
EXPERIMENT 2 – 6060 T5 ALUMINIUM



EXPERIMENT 3 – ONESTEEL FMS




820
85
50
6
226
10
10
Enclosure for rotary actuator mechanism
100
11
250
110
8
DO NOT SCALE DRAWING
REVISION
PRELIMINARY DESIGN
NOT FOR MANUFACTURE
EXPERIMENT_2_BASE
A3
SCOTT COX


820
236
100
100
50
100
8
600
110
DO NOT SCALE DRAWING
REVISION
SCOTT COX
PRELIMINARY DESIGN
NOT FOR MANUFACTURE
EXPERIMENT_3_BASE
A3

Appendix J

MATLAB Scripts

```
% WRITTEN BY SCOTT COX - 2013
% U1002971

% ENG4111 & ENG4112 Research Project Part 1 & 2

% EXPERIMENT 1

% The purpose of this script is to output theoretical results of conducting
% a shaft torsion experiment. This is to be used to select the most appropriate
% material and section for experiment 1.

clc, clear, close all          % clears the command window, clear all variables and
closes all open applications

Diameter=16;                  % Specifies the diameter of shaft (mm)
G=24000;                      % Specifies the modulus of rigidity of material (MPa)
S_y=140;                      % Specifies the shear yield strength of the material (MPa)
Percent_yield=70;             % Specifies the maximum percent of yield strength material
should be stessed to (%)
Shaft_length=600;             % Specifies length of shaft (mm)
Moment_arm=100;               % Specifieas lenght of moment arm (mm)

c=Diameter/2;
Tau_max=S_y*Percent_yield/100;

J=0.5*pi*c^4;                                   % (mm^4)
T_req=Tau_max*J/c;                              % (Nmm)
Force_req=T_req/Moment_arm;                     % (N)
Phi=(T_req*Shaft_length)/(G*J);                 % (Radians)
Phi_deg=Phi*180/pi;                             % (deg)

fprintf('\n')
disp(['Force required to produce Tau_max = ',num2str(Force_req),' N'])
fprintf('\n')
disp(['Angle of twist = ',num2str(Phi_deg),' degrees'])
```

Experiment 2 – Unsymmetric Bending (page 1)

```
% WRITTEN BY SCOTT COX - 2013
% U1002971

% ENG4111 & ENG4112 Research Project Part 1 & 2

% EXPERIMENT 2

% The purpose of this script is to output theoretical results of conducting
% a bending experiment with unsymmetrical material. This is to be used to select
% the most appropriate cross-section of material and the maximum mass which can be
suspended.

clc, clear, close all        % clears the command window, clear all variables and closes
all open applications

Height=40;                   % Specifies the height of the unequal angle section (mm)
Width=20;                    % Specifies the width of the unequal angle section (mm)
Thickness=3;                 % Specifies the thickness of the unequal angle section

Mass=6.5;                    % total mass suspended from end of beam (kg)
g=9.81;                       % Specifies value of gravity (m/s^2)
Load=Mass*g;

%for i=0:0.001:360;
Desired_orientation=0;       % Specifies ORIENTATION (deg 0-360)

if Desired_orientation >= 180
   Orientation=Desired_orientation-180;
else
   Orientation=Desired_orientation;
end

Shaft_length=600;            % Specifies length of shaft (mm)
E=70000;                     % Specifies the modulus of elasticity of material (MPa)
S_y=250;                     % Specifies the shear yield strength of the material (MPa)
Percent_yield=60;            % Specifies the maximum percent of yield strength material
should be stessed to (%)

Max_stress=S_y*Percent_yield/100;

%---------------------------------------------------------------------------
% calculate location of centroid (from orientation shown in report)

Area_1=Height*Thickness;
Area_2=(Width-Thickness)*Thickness;
Sum_area=Area_1+Area_2;

Z1_i=Thickness/2;
Z2_i=Thickness+((Width-Thickness)/2);

Y1_i=Height/2;
Y2_i=Thickness/2;
```

```
 ZA_1=Area_1*Z1_i;
YA_1=Area_1*Y1_i;

ZA_2=Area_2*Z2_i;
YA_2=Area_2*Y2_i;

Sum_ZA=ZA_1+ZA_2;
Sum_YA=YA_1+YA_2;

Z_bar=Sum_ZA/Sum_area;       % mm
Y_bar=Sum_YA/Sum_area;       % mm

%---------------------------------------------------------------------------
% Calculate second moment of inertia

b_1=Thickness;               % Breadth of area 1
d_1=Height;                  % Depth of area 1
b_2=Width-Thickness;         % Breadth of area 2
d_2=Thickness;               % Depth of area 2

Iz=(b_1*d_1^3/12+Area_1*(Y1_i-Y_bar)^2)+(b_2*d_2^3/12+Area_2*(Y_bar-Y2_i)^2);   % mm^4
Iy=(d_1*b_1^3/12+Area_1*(Z_bar-Z1_i)^2)+(d_2*b_2^3/12+Area_2*(Z2_i-Z_bar)^2);   % mm^4

%---------------------------------------------------------------------------
% Calculate the mixed moment of area / product of inertia (Izy)

Izy=(Area_1*(Z1_i-Z_bar)*(Y1_i-Y_bar))+(Area_2*(Z2_i-Z_bar)*(Y2_i-Y_bar));      % About
centroid

% To confirm see CRAIG.. page A16 (PDF)

%---------------------------------------------------------------------------
% Calculate angle theta which corresponds to the angle with which the major PCA alligns

Theta=0.5*atand(-Izy/((Iz-Iy)/2));

Orientation_max_axes=Orientation+Theta;
if Orientation_max_axes >= 180
    Orientation_max_axes = Orientation_max_axes - 180;
end

Orientation_min_axes=Orientation_max_axes+90;
if Orientation_min_axes >= 180
    Orientation_min_axes = Orientation_min_axes - 180;
end

%---------------------------------------------------------------------------
% Calculate Imin and Imax

R=sqrt(((Iz-Iy)/2)^2+Izy^2);
I_avg=(Iz+Iy)/2;

I_min=I_avg-R;
I_max=I_avg+R;
```

```
%--------------------------------------------------------------------------
% Calculates 'c' distance values for when section is orientated on PCA's

C_max=Z_bar/sind(Theta)+(Height-Y_bar-cosd(Theta)*(Z_bar/sind(Theta)))*cosd(Theta);
C_min=cosd(Theta)*(Width-Z_bar-tand(Theta)*(Y_bar-Thickness));

%--------------------------------------------------------------------------
% Calculates the maximum mass the section can support when moment is
% alligned with min PCA

Max_moment=Max_stress*I_min/C_min;
Max_end_load=Max_moment/Shaft_length;
Max_end_load_kg=(Max_moment/Shaft_length)/9.81;

%--------------------------------------------------------------------------
% Calculates deflection when moment is orientated with PCA's

Deflection_minaxes=Load*Shaft_length^3/(3*E*I_min);         % (mm)
Deflection_maxaxes=Load*Shaft_length^3/(3*E*I_max);         % (mm)

%--------------------------------------------------------------------------
% Resolve moments along PCA's min and max

Load_v=Load*cosd(Theta+Orientation);
Load_u=Load*sind(Theta+Orientation);

%--------------------------------------------------------------------------
% Nuetral axis orientation calculation

if Orientation_max_axes <= 90
    N_a=atand((I_max/I_min)*-tand(Theta+Orientation))+Theta+Orientation;           %
(degrees)
else
    N_a=atand((I_max/I_min)*-tand(Theta+Orientation))+Theta+Orientation-180;
% (degrees)
end

if Orientation_min_axes >= 90 && Orientation_min_axes < 90+Theta
    N_a=N_a-180;
end
%--------------------------------------------------------------------------
% Calculates the deflections perpendicular to each axes

Deflection_v=(Load_v*Shaft_length^3)/(3*E*I_max);
Deflection_u=(Load_u*Shaft_length^3)/(3*E*I_min);

Horizontal_deflection=Deflection_v*sind(Theta+Orientation)-
Deflection_u*cosd(Theta+Orientation);
Vertical_deflection=-
abs(Deflection_v*cosd(Theta+Orientation)+Deflection_u*sind(Theta+Orientation));

%--------------------------------------------------------------------------
```

Experiment 2 – Unsymmetric Bending (page 4)

```
% Outputs

clc
disp(['The maximum mass that can be supported on the end of the beam is ',
num2str(Max_end_load_kg),' kg'])
fprintf('\n')
disp(['Orientation is ',num2str(Desired_orientation),' degrees'])
fprintf('\n')
disp(['The theoretically calculated NA is ', num2str(N_a),' deg'])
fprintf('\n')
disp(['Vertical deflection = ',num2str(Vertical_deflection),' mm'])
disp(['Horizontal deflection = ',num2str(Horizontal_deflection),' mm'])
fprintf('\n')
disp(['Practical NA is ',num2str(atand(Horizontal_deflection/-Vertical_deflection)),'
deg'])
%end
```

```
% WRITTEN BY SCOTT COX - 2013
% U1002971

% ENG4111 & ENG4112 Research Project Part 1 & 2

% EXPERIMENT 3

% The purpose of this scriptis to output theoretical results of conducting
% a normal stress experiment. This is to be used to select the most appropriate
% material and section for experiment 1.

clc, clear, close all     % clears the command window, clear all variables and closes
all open applications

Width=25;                 % Specifies the diameter of shaft (mm)
Thickness=12;
E=200000;                 % Specifies the modulus of rigidity of material (MPa)
S_y=360;                  % Specifies the shear yield strength of the material (MPa)
Percent_yield=89;         % Specifies the maximum percent of yield strength material
should be stessed to (%)
Beam_span=600;            % Specifies length of shaft (mm)
g=9.81;                   % Specifies value of gravity (m/s^2)

I_value=(Width*Thickness^3)/12;                           % Calculates the second
moment of inertia

Max_moment=S_y*Percent_yield/100*I_value/(Thickness/2);   % Calculates the maximum
moment that beam can support

Max_load=4*Max_moment/Beam_span;                          % Calculates the maximum
(N) load the beam can carry

Max_load_kg=Max_load/g;

Max_deflection=Max_load*Beam_span^3/(48*E*I_value);       % Calculates the max beam
deflection (mm)

Max_normal_stress=S_y*Percent_yield/100;

Max_normal_strain=Max_normal_stress/E;

% Displays

disp(['Maximum beam deflection will be ',num2str(Max_deflection),' mm'])
fprintf('\n')
disp(['Maximum load the beam can be subjected to is ',num2str(Max_load),' N'])
fprintf('\n')
disp(['Maximum normal stress in the beam will be ',num2str(Max_normal_stress),' MPa'])
fprintf('\n')
disp(['Maximum normal strain in the beam will be ',num2str(Max_normal_strain)])
```